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HAND-BOOK

OF

American Gas-Engineering Practice

BY

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PREFACE.

AMERICAN gas engineers have for a long time deplored the lack of a work treating on the technology of modern gas supplies from a practical standpoint, and framed in such a manner as to constitute a book of reference for those engaged in the industry, as well as for students.

To supply his personal needs, the author began, several years ago, a compilation of material which, accumulating and being classified, has taken the shape of the handbook which he now presents to the profession, with every confidence that it will prove of value and be welcomed. His intention is to extend and revise future editions so that the final result will be a complete handbook of gas engineering, covering the minute details of every branch of the industry.

The general plan of the work is as follows:

Water-gas manufacture, from the consideration of the fuels and materials to the gas-holder. The treatment is throughout practical rather than theoretical, and the chapters on these subjects would be understandingly read by gas-makers, foremen, and manual operators of the works, a feature which the author considers of considerable importance. Much of such practical detail of operation has not heretofore been published.

The next division is devoted to gas distribution, which is gone into at length. It includes also a discussion of the various gas-burning appliances and their attendant data, the whole treated in the same practical way as the chapters on manufacture.

Other methods of gas manufacture are reserved for subsequent editions, but distribution as here treated is applicable to every field of gas engineering. Specifications for mains, joints, piping, and standard sections will be found of peculiar interest and convenience.

The final division on technical data contains much theoretical, mathematical, and technical information on the properties of gases and steam, calorific values, temperature data, testing corrections, tables, etc. The sources of this data have been carefully considered and are believed to be reliable.

The subject of proprietary patents and apparatus not in general use were, for lack of space, omitted, which fact also prevented the including of many things which would have been of interest, these also being left for future editions.

The author depends on the readers of this handbook for material assistance in improving its present form and extending its usefulness, and welcomes any suggestions and criticisms of his readers that may enable him to keep the ensuing editions abreast of the progress of the industry.

The author desires to acknowledge the assistance of the many engineers connected with gas companies and manufacturing concerns. The uniform courtesy with which the author's requests for information have been invariably met is a source of much gratification to him, and he desires to here express his great appreciation.

M. NISBET LATTA.

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PART I.

WATER-GAS MANUFACTURE.

CHAPTER I.

THE GENERATOR.

THE burden of this work will bear upon water-gas as manufactured by the Lowe process, taking up the work in the sequence of manufacture and tracing the course of the gas throughout the operation.

Apparatus.—The apparatus used is principally of the Lowe type, consisting of a generating vessel, carburetter, superheater, wash-box, condenser and scrubber, relief-holder, exhauster, purifier, and holder. These water-gas machines are compact and the vessels are side by side in one building.

The following table shows the sizes and capacities of the standard Lowe process water-gas apparatus as manufactured by the United Gas Improvement Co., the largest water-gas apparatus manufacturers in the world:

WATER-GAS APPARATUS (U. G. I. CO.).

Double Superheater, Diameter Feet.	Generator Carburetter, Diameter Feet.	Generator, Diameter Feet.	Carburetter, Diameter Feet.	Superheater, Diameter Feet.	Daily Capacity, Cubic Feet per 24 Hours.
3	3	..	..	3	50,000
4	4	..	..	4	100,000
4	4	..	..	4	125,000
5	..	5	5	5	250,000
6	..	6	6	6	400,000
6.5	..	7.5	7	7	750,000
8.5	..	8.5	8	8	1,000,000
9	..	9	9	9	1,250,000
11	..	11	11	11	2,000,000

Another variation of this type is made by the Gas Machinery Co., who issue the following table of sizes. These capacities are approximate only, as the actual amount of gas which can economically be made in a carburetted water-gas apparatus depends upon the kind of fuel and oil used, blast pressure, steam supply, candle power desired, etc.

WATER-GAS APPARATUS (GAS MACHINERY CO.).

Diameter of Generator Shell, Feet.	Height of Operating Floor, Ft. Ins.	Capacity in Cubic Feet per 24 Hours.	Size of Building Suitable for Two Sets, Feet.	Usual Height of Building to Bottom of Roof-trusses, Feet.
3.5	12 3	60,000 to 75,000	23×30	20
4	13 3	100,000 " 125,000	24×32	22
5	13 3	175,000 " 250,000	27×40	25
6	14 3	325,000 " 425,000	30×46	28
7	14 3	500,000 " 650,000	33×52	30
8	14 3	750,000 " 900,000	36×56	30
9	15 3	1,000,000 " 1,250,000	38×64	30
10	16 3	1,300,000 " 1,600,000	42×78	32
11	16 3	1,600,000 " 1,900,000	48×84	32

Fuels.—Generator fuels are generally of two kinds: coal (anthracite) and what is generally known as 48-hour oven coke. The best results from either of these are generally obtained from a glossy black coal, egg-size and passing through about a 3-inch-mesh screen, or from a silvery-gray coke of about the same diameter. The chief defect which the coal may possess lies in the amount of sulphur which it contains, a large percentage of sulphur producing not only a very sulphurous gas, but also forming a hard and intractable clinker. "Twenty-four-hour gas-house coke" is sometimes used in emergency, but coke of this class is usually too soft and does not retain the heat in the generator while steam is blown through it during the "run," thereby creating a strongly acid gas.

Oil.—It is the custom of a number of companies throughout the country to introduce the oil used for enriching the water-gas directly into the generator on all up-runs. This is supposed to save the brick of the carburetter, and, inasmuch as the oil is vaporized at the same heat and under the same conditions under which the steam is decomposed, the vapor tension is assumed to be approximately the same, and the oil-gas and water-gas being thus combined under similar conditions at an equal temperature form a more intimate mixture. In addition to this, when the

gases are formed in the generator the carburetter is saved the chilling effect due to vaporizing the oil, and is thus utilized as an additional superheating chamber, providing for the gases an extraordinary amount of fixing surface and prolonging the period of fixation travel.

Practice differs very greatly in regard to this method of working. It is certain, however, that in small works occasional use of this method is of advantage, inasmuch as it not only relieves the carburetter of the immediate vaporization of the oil, but allows any carbon which may have already accumulated upon the brickwork of the carburetter to burn off. There should be, at least in all small works where continuous running is a necessity and any delay caused by stoppage of the oil-spray is a serious contingency, a flexible connection with the oil-pipe which can be attached to a spray tapped into the lid of the generator coaling-valve cover.

Where oil is used to substitute solid fuel in manufacturing water-gas, the amount necessary, using crude oil as a basis, is variously estimated at from 12 to 15 gallons per 1000 cu. ft. At least one-third of this oil is consumed for the heating (or during the blasting period) of the apparatus.

Blasting.—The question of the coaling periodicity is one over which there is considerable diversity of opinion. It should undoubtedly depend upon the condition of the incandescent fuel-bed and be determined by the gas-maker. The fires should be thoroughly cleaned and freed of all possible clinker at least twice a day. In blowing air through the fuel-bed during the first blasting, in putting a generator in operation, many analyses of gas show that it is a rare thing for the generator fire to be thoroughly in condition for the first run, the result invariably showing large quantities of carbon dioxide, and going to prove that the duration of the blast was too short.

The author has indeed never known a gas-maker who was sufficiently careful when getting up this first heat, and especially recommends that before turning on steam the coaling-valve be opened and the fire examined to see that there is no "green" coal visible which has not attained the proper heat, and that the generator fuel-bed has a temperature corresponding to a bright orange color. Gas-makers are often prevented from sufficiently blasting their generators for fear of overheating the other chambers. It is better to operate with a light blast for a longer period through the generator than with a strong blast for a shorter time, and under some conditions it has been advisable to put a light blast through the generator with the coaling-valve remaining open. Should, however, the carburetter become unduly hot

during this blasting period it may be "blown cold" by an excessive blast through the carburetter while a light generator blast is maintained.

There cannot be too much emphasis laid upon the proper heat being obtained in the generator before the commencement of runs, as insufficient heat and improper decomposition of the steam, together with the chilling effect of "green" or insufficiently heated coal, will invariably produce an excess of oxygen, while the carbon, unless incandescent, fails to combine, thereby forming carbon dioxide instead of the desired monoxide.

Blowers.—Blowers should be of ample capacity and if possible in duplicate. The location of a blower should be removed as far as possible from dust, as its bearings at high speeds require close attention and should be kept in the very best condition, their oilways being examined periodically, for they may perhaps be termed the "critical point" of the works. It is sometimes necessary, in case of their heating, to play a small stream of water upon them; ice may be of advantage; cylinder-oil, castor-oil, or even urine is used, the latter being employed with most remarkable results, as the salts therein contained crystallize in the heat and form a viscous bearing between the shaft and the box. Dixon's graphite compounds are also valuable.

The following table gives the principal dimensions to be specified in securing a blower of the Sturtevant type for supplying air-blast to water-gas generators; they are special extra heavy:

DIMENSIONS OF BLOWERS.

Number of Blower.	Diameter and Face of Pulley in Inches.	Maximum Revolutions per Minute.	Maximum Pressure.		Blower only. Outside Diameter of Outlet in Inches.	Blower on Adjustable Bed with Sliding Outlet.	
			Ounces per Square Inch.	Inches of Water.		Outside Diameter Outlet with Horizontal Discharge in Inches.	Dimensions of Oblong Pipe Connection for Up-blast Discharge in Inches.
4	5×7	3,670	12	20.8	10[illegible]	11[illegible]	10[illegible]×15[illegible]
5	7×8	3,420	14	24.2	12[illegible]	13[illegible]	12[illegible]×18[illegible]
6	8×9	3,330	16	27.7	14[illegible]	15[illegible]	14[illegible]×21[illegible]
7	9×11	2,750	16	27.7	16[illegible]	17[illegible]	16[illegible]×24[illegible]
8	10×13	2,270	16	27.7	18[illegible]	20[illegible]	18[illegible]×27[illegible]
9	12×15	2,040	16	27.7	21[illegible]	23[illegible]	21[illegible]×32[illegible]
10	14×16	1,700	16	27.7	24[illegible]	25[illegible]	24[illegible]×36[illegible]

NOTE.—These Sturtevant special extra-heavy Blowers are for supplying blast to water-gas generators.

The outside dimensions of the shells of these blowers are the same as those of the ordinary gas-blowers given in Catalogue No. 82, but the pulleys are larger and the hangers or supports for the bearings are longer.

Bearings of the blower or engine, where made of babbitt metal, should be made at a single pouring of the metal, no interval being allowed. After being poured, the bearing should be heavily peened, this having a tendency to make the metal in the bearing more homogeneous. Where engine or blower bearings have a tendency to run hot, cylinder-oil or, better, castor-oil may be temporarily used. At the first opportunity, however, the bearings should be opened and the oil-ducts examined.

Generator Blast Pressures. — The difference in pressure between the top and bottom of a water-gas generator having a 6 to 7 ft. deep fuel-bed will vary from 5 in. to 8 in., depending upon the nature of the fuel used and the heat in the machine. Six inches pressure is a good average, while a lesser difference than 5 in. tends to show a lack of even distribution on the part of the fire-bed, the presence of blow-holes, etc.

High blast pressure has a tendency to increase clinkers; when necessary this may be counteracted by alternating or reversing the steam in the middle of each run. Too much stress cannot be laid upon the necessity for a thorough cleaning of the fire, a neglect of this, more than any other feature, tending toward clinker formation. Where generators are intermittently in service they should be gradually brought up to their heat, the increase in temperature being by slow degrees and not forced. From a standpoint of production it is not good practice to vary the direction of steam during a run, except in instances of excessive clinker formation, greater production being obtained per hour by varying the alternate runs by a down-run every third or fourth time.

Where fan-blowers are driven by electricity common practice demands a consumption of about 1 k.w. per 1000 cu. ft. of gas manufactured.

Regarding the pressure of blast to be maintained upon the generator of water-gas sets, the following theory has been the result of a number of experiments by the author:

A medium blast pressure should as nearly as possible be maintained because, should the blast pressure increase above about 18 in., combustion of fuel becomes too rapid, producing too much heat and too rapid consumption of fuel, together with clinker. Should the blast pressure fall below the minimum, about 12 in. of water, the following phenomena will be observed:

The rate of flow of the blast being insufficient in pressure to carry away from the generator the CO first produced by combus-

tion, and which should be burned to CO_2 by the additional air supply provided at the carburetter and superheater, furnishing fuel respectively to these parts of the apparatus, a large portion of this product remains inertly in the generator and is gradually burned from CO to CO_2, or, in other words, the complete combustion of C to CO_2 takes place in the generator instead of being distributed throughout the apparatus. Primary combustion should take place in the generator, and secondary combustion in the two machines following in series.

The result of this additional combustion is the production of excessive heat in the generator, greatly deteriorating the lining, etc., and at the same time causes a failure on the part of the generator to supply sufficient gas for the secondary combustion of the other machines. When the blast pressure is ample these gases are kept moving and carried along by the draught, and are in due process consumed. The capacity of the generator is usually rated from the area of the grate, being generally figured approximately at 20,000 cubic feet per square foot of grate surface per 24 hours.

It is recommended in all instances to run the steam-pipe to the generator, of a size not smaller than 1.5 in. diameter, reducing it at the generator inlet by a ¾-in. valve.

Clinker.—A word may be said here concerning one of the greatest annoyances to the gas-maker, as well as hindrance to obtaining good results—the formation of clinker, which occurs especially with highly sulphurous coals and is at times almost impossible to control. Besides the use of heavy clinkering-bars, long-handle cold chisels, and sledges, there are numerous chemical compounds used for clinker disintegration. Oyster-shells and unslaked lime are used for this purpose in a large number of works, but are not especially efficacious. Perhaps one of the surest methods is that of leaving the steam turned on upon the bottom of the generator with the valve opened, say, a quarter of a turn. This method, if pursued for ten or twelve hours, invariably softens the clinker and is generally known as "rotting." Its one objection is the softening and decomposition of the fire-brick.

The author suggests a method having none of these disadvantages and which he has used with invariable success. On the end of a pipe of about ¾ in. diameter and 12 or 15 ft. in length he affixes a funnel, places the end of the pipe upon a clinker, where it joins the fire-brick and pours through the funnel a mixture of 12 pints of water and 1 of common vinegar, moving the pipe about to attack various points of the clinker and repeating the pouring, when it becomes soft enough to yield to a heavy clinker-bar.

Generator Steam.—It has been generally agreed that the temperature of the fire, which should be at least 1800° F., and the

control of the rate of flow of the steam determine the composition of the gas within the limits usually applied to water-gas practice. It is doubtless nearly correct to assume the amount of steam dissociated as about 15.4 or 15.5 lbs. per 1000 cu. ft. of final gas.

The steam should unquestionably be as dry as possible, and for this purpose the initial boiler pressure should be not lower than 90 and not exceeding 120 lbs. All steam-piping should be covered, preferably with magnesia covering. A separator should be placed near the entrance of the generator, an extremely satisfactory kind of which is the Cochrane horizontal type; connected with this, the Bundy steam-trap has given the author the best results. This trap is perfectly automatic, easily adjusted, and operates with a balance-arm; one alone will take care of the water from a half-dozen or more separators about the works and, if placed at the proper elevation, will return condensation into the boiler.

One of the greatest difficulties in the manufacture of gas is the proper regulation of the amount of steam to be admitted into the generator. Too little steam retards gas production or limits the amount of gas made by the generator, while an excess of steam carries off and wastes an enormous amount of heat from the generator fire, the exact amount depending upon the temperature of the gas when leaving the superheater. For example, suppose the steam entered the generator at 331° F. and the gas left the superheater at 1450° F., then each pound of undecomposed steam carried from the superheater about 537 B.t.u. Assuming the quantity of waste steam to amount (as has been cited in an experiment by Mr. Morris) to 14.8 lbs. per 1000 cu. ft. of gas, the waste heat per 1000 cu. ft. manufactured would amount to nearly 8000 B.t.u., or about one-half of the total energy required for the decomposing of the steam in the finished gas.

Too little steam will leave the fire in a condition favorable to the formation of hard and obdurate clinker, greatly increasing the length of the necessary cleaning period and reducing materially the gas made per day for the apparatus, and destroying the linings.

The quantity of excess steam (steam admitted to the generator and not decomposed) is best determined by an analysis of the gas for CO_2, the amount of carbonic acid gas being in direct ratio to the excess of steam.

To determine the rate of flow of steam admitted to the generator satisfactory use may be made of the following device. The steam-pipe is disconnected from the generator shell and immersed in a cask containing a known weight of water, the cask being set upon portable scales, so that the steam-pipe dips into the water the number of inches corresponding to the gas pressure in the

generator when and where the steam is admitted. The total length of steam-piping and total length of turns are the same as when the pipe is connected to the generator, and the quantity of steam flowing into the cask per unit of time is read on the scale-beam. Separate determinations are made of the steam supplies at the upper and lower connections to the generator. The rates thus found may be taken as approximately correct for conditions of actual generator use.

Under operating conditions the use of the Sargent Steam Meter will be found very convenient for current reference, and as a standard of comparison and of operation.

This meter is tested and calibrated with commercially dry steam containing about 2% of moisture, and of course any variation in this moisture shows up as an error. To all practical purposes however, allowing for the personal error possible in observation, under any ordinary conditions of operation, the maximum variation of this meter does not exceed 3%, which is near enough to furnish a very satisfactory standard of operation and comparison.

The operation of the meter is as follows: When no steam is flowing through the pipe the mercury in the cistern and in the tube is on a level, that in the tube registering zero. The steam beginning to flow, its velocity places a pressure upon the cistern, causing the mercury to rise in the tube in direct ratio to said velocity and proportionate to the weight flowing through.

To read the meter: Note the pressure on the gauge, revolve the drum containing the dial, by the hand-wheel, until the pressure on the top of the drum corresponding to the gauge is behind the tube, then the top of the column of mercury will indicate the pounds of steam or horse-power flowing through per unit of time.

The quantity of steam decomposed, and so present in the finished gas, is determined from an analysis of the gas, the water-vapor present in the finished gas being dependent upon the temperature.

A direct measure of the excess steam used per 1000 cu. ft. of gas made is effected by collecting all the condensation (tar and water) that occurs. If no water is introduced into the system between the carburetter and the gas-holder, the water condensed and measured gives directly the data for the excess steam used in the generator. This figure is one most easily and accurately ascertained, and it furnishes a constant check upon the operation of the generator.

It is needless to point out that wet steam carrying with it water in the form of fog would largely increase the oxygen factor

in the gas, thereby running up the production of CO_2. To overcome this it is necessary, as before stated, to procure the dryest possible steam by using pipe coverings, steam separators, and a high initial boiler pressure. On the other hand this boiler pressure has certain drawbacks, of which rapidity of flow of the steam through the incandescent carbon is the chief. Too great a velocity will produce blow-holes or open channels through the carbon bed and cause the steam to escape undecomposed, as well as an uneven distribution of steam throughout the fuel-bed, which, for the best results, should be as uniform as possible. To overcome these difficulties it has occurred to the writer to place a reducing-valve (such as the Mason type) on the steam-pipe just prior to its admission into the separator; such a valve will reduce a pressure of about 100 lbs. at the boiler to a terminal pressure of 45 or 50 lbs. in the generator, which would materially reduce the velocity of flow and tend to superheat.

It has also occurred to the writer that it might be well to introduce the steam into the generator by a number of small jets similar to the radial sprays on scrubbers, which would distribute the steam more generally over the cross-section of the generator. He has, however, no information as to any such experiment having ever been made. However, it is well known in gas manufacture that decreasing velocity of gas flow increases the intimate union and thorough combination of the substances involved.

It is needless to point out the necessity of having extra-heavy pipe and heavy brass fittings on all steam connections. In the case of both oil and steam connections the author has had specially good service from Lunkenheimer valves. Between the generator and the carburetter asbestos-board gaskets should be used in the connections, and for these and other packings there is none better than Vulcabeston.

Steam Flow.—Drs. Strache and R. Jahoda, in their work on the "Theory of the Water-gas Process," place great emphasis on the rate of flow of the steam, and imply that Dr. Bunte in his work did not properly appreciate the result that different rates of flow would have upon the gas made thereby. Among other remarks they write as follows: That at a particular temperature both the steam passing through undecomposed and the proportion of carbonic acid in the gas largely increase with the increase in the rate of the steam flow, and also increase in direct ratio. Secondly, that, a constant rate of flow of the steam being secured, both the CO_2 and the steam excess decrease with an increase of temperature. That at low temperature the CO_2 and the excess may be reduced by reducing the rate of flow of the steam.

In verification of the above they give the following table:

Rate of Flow of Steam.	Minute of Run at which Observation was Made.	Temperature of Generator, Deg. C.	Temperature of Effluent Gas, Deg. C.	Undecomposed Steam, Percentage of Total.	Carbonic Acid Gas, Per Cent.	Efficiency of Run, Per Cent. of Maximum.	Total Efficiency, Per Cent. of Maximum.
0.58	2	790	228	1.3	7.1	....	....
	5	788	207	2.7	4.6	69.0	54.5
	12	785	214	9.1	6.2	67.0	53.0
	20	778	221	21.8	8.9	60.5	47.0
	35	740	200	48.8	13.0	42.0	33.0
4.40	1	860	390	4.0	2.2	92.0	75.0
	3	850	390	10.0	2.7	91.0	74.0
	6	816	365	22.0	4.5	90.0	75.0
	9	810	365	24.0	6.6	88.0	73.5
	12	796	408	28.0	8.7	86.3	71.8
	16	775	415	45.5	11.4	83.5	71.0
7.50	1	...	530	...	2.7	....	....
	3	...	515	11.7	4.6	90.0	69.0
	6	...	490	27.4	9.6	88.0	70.5
	9	...	470	54.2	12.6	78.0	63.0
	12	...	470	62.1	15.6	73.0	59.0
8.10	1	...	515	....	3.4	....	....
	3	...	510	1.3	5.5	91.0	71.0
	6	...	500	19.7	11.2	88.0	70.0
	9	...	475	....	14.9	86.0	71.0
	12	...	470	47.9	17.3	82.0	68.0
13.00	1	...	470	7.6	3.4	92.0	73.5
	5	...	500	11.9	5.6	91.5	73.0
	6	...	500	32.1	9.0	92.0	71.5
13.40	1	900	470	14.3	5.0	91.5	72.5
	3	880	478	27.9	6.9	89.0	71.0
	6	830	475	48.9	9.4	84.0	67.5
	9	800	493	62.8	13.1	77.0	62.5
	12	780	492	69.6	13.9	74.0	60.0
17.00	1	...	600	8.1	2.6	91.0	69.0
	3	...	590	25.8	5.3	88.0	67.0
	6	...	560	48.5	11.8	81.0	62.0
	10	...	540	73.6	14.9	67.5	51.0
	12	...	530	76.5	15.2	65.0	51.0
21.20	1	945	680	8.6	4.4	90.5	70.5
	3	910	650	41.3	6.8	83.0	63.0
	6	865	620	48.6	8.7	81.0	61.5
	12	805	590	70.1	14.4	68.5	53.5
	16	780	...	77.6	17.6	61.5	47.0
21.30	1	...	680	....	2.1	....	....
	3	...	650	23.0	6.0	90.0	70.5
	6	...	620	63.3	11.8	72.5	54.0
	10	...	595	77.1	14.8	61.5	46.0

The researches of Harris under the direction of Dr. Bunte were tabulated as follows:

Temperature, Degrees C.	Composition of Gas, Volumes Per Cent.			Water-vapor, Per Cent.	
	H	CO.	CO_2.	Decomposed.	Undecomposed.
694	65.2	4.9	29.8	8.8	91.2
758	65.2	7.8	27.0	25.3	74.7
838	62.4	13.1	24.5	34.7	65.3
838	61.9	15.1	22.9	41.0	59.0
861	59.9	18.1	21.9	48.2	51.8
954	53.3	39.3	6.8	70.2	27.2
1010	48.8	49.7	1.5	94.0	6.0
1060	50.7	48.0	1.3	93.0	7.0
1127	50.9	48.5	0.6	99.4	0.6

Steam Supply.—Steam should never be turned on the generator for a " run " until the top of the fire appears to be in a thorough state of combustion and free from dark (or "green ") coal, as viewed through the sight-cock in the coaling-lid of the generator.

Excessive heat in the generator, and indirectly the entire set, may be speedily " killed " by adding, in addition to the regular up-steam on an up-run, say a quarter of a turn of opening on the down-steam valve. It may also be reduced by varying the amount or period of the blast, or, conversely, the variation of the regular steam admitted.

The percentage of gain resulting from the increased temperature of feed-water in any particular case may be calculated by the formula

$$\text{Gain (per cent.)} = \frac{100(T-t)}{H-t},$$

where H = total heat in steam at boiler pressure, reckoned from 0° F.;
T = temperature of feed-water after heating;
t = temperature of feed-water before heating.

The quality of the steam supplied is quite important, the properties being as follows:

Saturated Steam.—Saturated steam is steam in contact with and containing entrained water at the same temperature as the steam itself. The name may be also applied to the steam on the point of condensation, even when this steam is to all appearances perfectly "dry " (not containing water in mechanical suspension), as long as the pressure and temperature remain un-

changed; but the slightest change in either of these two conditions will cause condensation on the part of a portion of the steam. Therefore, should a given volume of saturated steam be made to occupy a smaller space, the temperature remaining unchanged, the pressure will also remain unchanged, as enough of the steam will be condensed in the water to equalize the reduction of volume by the change of space occupied. Saturated steam is therefore not a permanent gas, inasmuch as it cannot be compressed under a constant temperature without a change resulting to its physical nature.

Superheated Steam.—A good definition of superheated steam is as follows: "Steam which for the same pressure has a greater temperature, and for any particular weight a greater volume, than saturated steam at the same pressure." It is produced by the vaporizing or gasifying of the water out of the steam molecule of saturated steam. Therefore, if its pressure is kept constant it tends to expand as its temperature increases. In some respects it is thus similar to a permanent gas; that is, if compressed under constant temperature, the pressure will at first increase inversely as the volume. This is, however, within limits; for, as the compression continues, the steam finally reaches the point of saturation, and thereafter the pressure cannot be increased by further compression under a constant temperature.

The chief difficulty in the generation of superheated steam is to secure material for the superheater which will withstand the intense heat of the burning gases on the one side and the steam on the other. This difficulty has made its general use hitherto impracticable. Generally speaking, horizontal boilers produce steam strongly saturated, while vertical boilers have a tendency towards superheating.

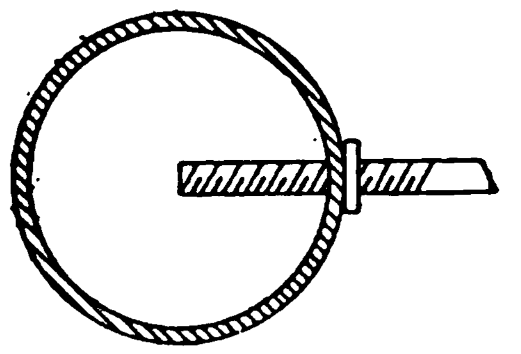

FIG. 1.—Steam Sampling-pipe.

Quality of Steam.—The quality of steam depends upon the quantity of heat it contains. It is wet if it contains fog or drops of water, dry if it contains just enough heat to keep it so, and superheated when it contains more heat than necessary to do so. Thus if a sample of steam is obtained and condensed, measuring the heat given up and the water produced, the B.t.u. per pound of water can readily be calculated. The process by which this test is made is called steam calorimetry and the apparatus is a calorimeter. The throttling calorimeters are more accurate for steam containing very little moisture and superheated steam, but the separating calorimeter is best for general purposes. To obtain a sample of steam the steam-pipe is tapped and a sampling-pipe

with a long thread screwed in until the end reaches the center of the steam-pipe. In the condensing types the weight of the apparatus and its specific heat must be known. This is obtained by adding a known weight of heated water, noting the rise in temperature, and what it should have been if the temperature of the water alone were considered. The difference divided by the final temperature and multiplied by the weight of the water will give the water equivalent of the calorimeter vessel which must be added to that of the water in the vessel.

Barrel Calorimeter.—This consists of a platform scales on which is a barrel into which dips a steam-pipe perforated near the bottom. The barrel should be large enough to hold 450 lbs. of water, although only about 360 lbs. are put into it. First let steam enter until the temperature of the water is about 130° F. to warm the barrel; empty it and add exactly 360 lbs. of water, taking its temperature immediately, removing the steam-pipe and hose and warming it up with steam; insert again into the water and note the temperature of the water until it is about 110° F., when the steam must be turned off and the weight noted as well as the temperature. The increased weight will be due to the weight of steam condensed, and the increased temperature to the heat held by the steam. The quality of the steam is then found by the following formula:

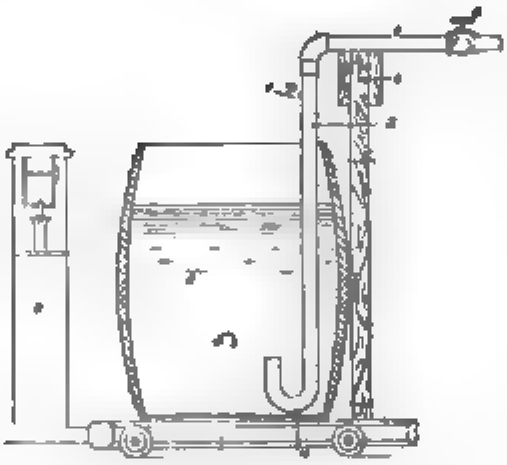

Fig. 2.—Barrel Calorimeter.

$$Q = \frac{d}{w} = \frac{1}{l}\left[\frac{W+k}{w}(t_2 - t_1) - (t - t_2)\right],$$

where Q = proportion by weight of pure dry steam in the sample;
d = weight of dry steam in the sample condensed;
W = weight of condensing water in barrel, 360 lbs.;
w = weight of steam and water from steam-pipe;
t = temperature of the steam at the gage pressure noted, to be found in steam tables;
t_1 = initial temperature of condensing water;
t_2 = final temperature of water after steam is condensed;
l = total latent heat of steam at pressure of test to be found in steam tables;
k = water equivalent of calorimeter.

Barrus Throttling Calorimeter.—The following description of a form of throttling calorimeter designed by Geo. H. Barrus of Boston will be found in Babcock & Wilcox Co.'s publication "Steam":

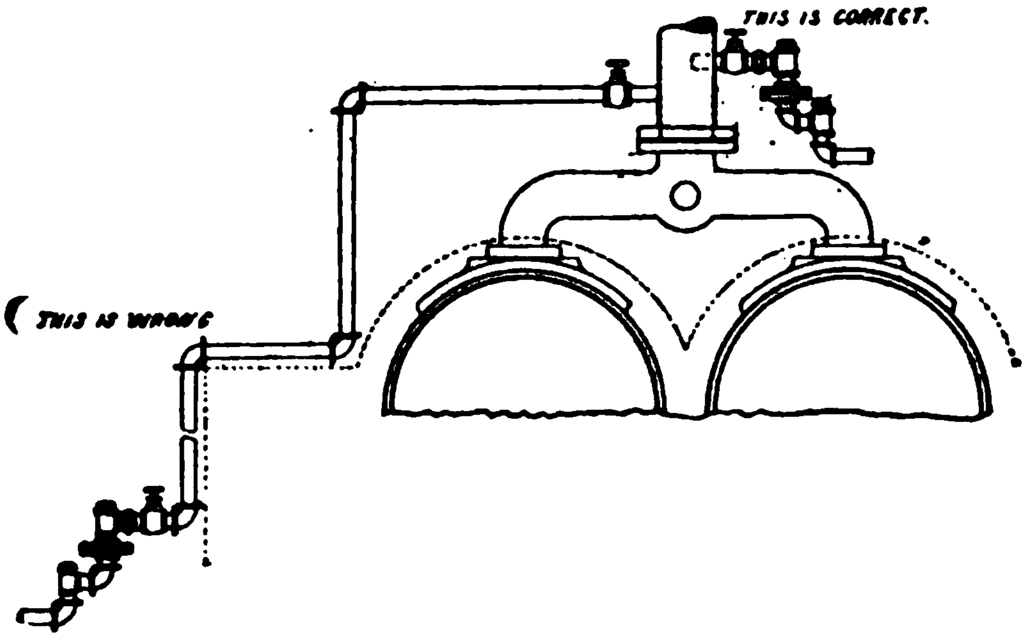

FIG. 3.—General Arrangement of Barrus Throttling Calorimeter.

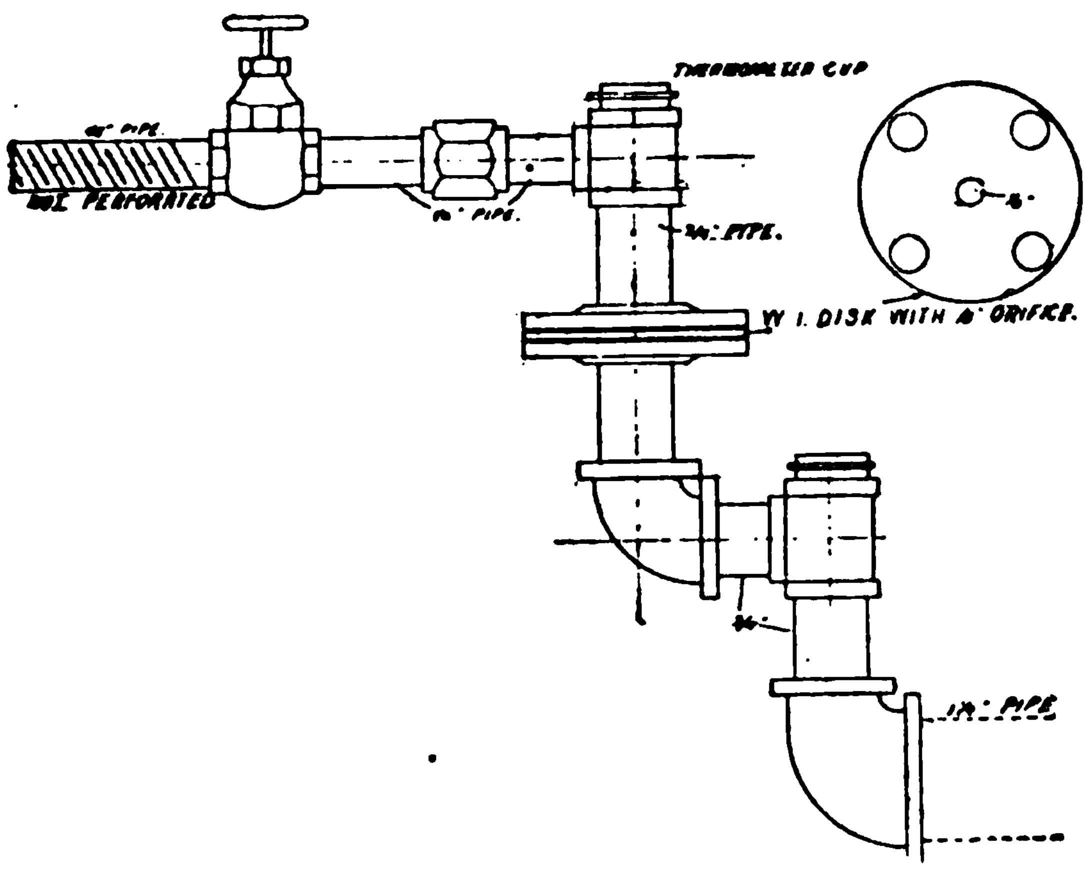

FIG. 4.—Detail of Barrus Throttling Calorimeter.

"Steam is taken from a $\frac{1}{2}$-in. pipe provided with a valve and passes through two $\frac{3}{4}$-in. tees situated on opposite sides of a $\frac{3}{4}$-in. flange union. A thermometer cup or well is screwed into each of these tees, and a piece of sheet-iron perforated with a $\frac{1}{8}$-in. hole in the center is inserted between the flanges and made tight with rubber or asbestos gaskets, which also act as non-conductors of heat. For convenience a union is placed near the valve as shown, and the exhaust steam may be led away by a short $1\frac{1}{4}$-in. pipe,

shown in the illustration by dotted lines. The thermometer wells are filled with mercury or heavy cylinder-oil, and the whole instrument from the steam-main to the 1¼-in. pipe is well covered with hair felt.

"Great care must be taken that the ⅛-in. orifice does not become choked with dirt, and that no leaks occur, especially at the sheet-iron disc, also that the exhaust-pipe does not produce any back pressure below the flange. Place a thermometer in each cup, and, opening the ½-in. valve wide, let steam flow through the instrument for 10 or 15 minutes; then take frequent readings on the two thermometers and the boiler gauge, say at intervals of one minute.

"The throttling calorimeter depends on the principle that dry steam when expanded from a higher or lower pressure without doing external work becomes superheated, the amount of superheat depending on the two pressures.

"If, however, some moisture be present in the steam, this must necessarily be first evaporated and the superheating will be proportionately less. The limit of the instrument is reached when the moisture present is sufficient to prevent any superheating.

"Assuming that there is no back pressure in the exhaust, and that there is no loss of heat in passing through the instrument, the total heat in the mixture of steam and moisture before throttling, and in the superheated steam after throttling, will be the same and will be expressed by the equation

$$H-\frac{xL}{100}=1146.6+0.48(t-212),$$

$$x=\frac{H-1146.6-0.48(t-212)}{L}\times 100,$$

in which x = percentage of moisture; H = total heat above 32° in the steam at boiler pressure; L = latent heat in the steam at boiler-pressure; 1146.6 = total heat in the steam at atmospheric pressure; t = temperature shown by lower thermometer of calorimeter; 212 = temperature of dry steam at atmospheric pressure.

"**Calibration.**—Theoretically the boiler pressure is indicated by the temperature of the upper thermometer, but owing to radiation, etc., it is usually too low, and it is better to use the readings of the boiler gauge, if correct, or, better still, to have a test-gauge connected on the ½-in. pipe supplying the calorimeter.

"If the instrument be well covered, and there is as little radiating surface as possible, the above assumption that there is no loss of heat in passing through the instrument may be nearly, though never quite, correct. On the other hand it is possible to be

very far from correct, and, to eliminate any errors of this kind, Mr. Barrus recommends a so-called 'calibration' for dry steam. This, again, involves an assumption which is open to some doubt, which is that steam, when in a quiescent state, drops all its moisture and becomes dry. No other practical method, however, has been proposed, and this is therefore the only method used at the present time. Some engineers, however, refuse to make any calibration, but instead make an assumed allowance for error.

"To make the calibration close the boiler stop-valve, which must be on the steam-pipe beyond the calorimeter connection; keep the steam pressure exactly the same as the average pressure during the test for at least fifteen minutes, taking readings from the two thermometers during the last five minutes. The upper thermometer should read precisely the same as during the test, and the lower thermometer should show a higher temperature; this reading of the lower thermometer is the calibration reading for dry steam, which we will call T.

"Calculation of results, allowing for radiation, by calibration method is made by this formula:

$$x=\frac{0.48(T-t)}{L}\times 100,$$

in which x = percentage of moisture; T = calibration reading of lower thermometer; t = test reading of lower thermometer; L = latent heat of steam at boiler pressure.

"The method of taking a sample of steam from the main is of the greatest importance, and more erroneous results are due to improper connections than to any other cause. The sample should be taken from the main steam current of the steam ascending in a vertical pipe. Avoid perforated and slotted nipples and use only a plain, open-end nipple projecting far enough into the steam-pipe to avoid collecting any condensation that may be on the sides of the pipe. Take care that no pockets exist in the steam-main near the calorimeter in which condensation can collect and run down into the sampling-nipple. Make connections as short as possible. "As mentioned above, there is a limit in the range of the throttling calorimeter which varies from 2.88% at 50 lbs. pressure to 7.17% at 250 lbs. When this limit is reached a small separator may be interposed between the steam-main and the calorimeter, which will take out the excesses of moisture. By weighing the drip from the separator and ascertaining its percentage of the steam flowing through, and adding this to the percentage of moisture in the steam, the total moisture may be ascertained.

It is seldom, however, in a well-designed boiler that any but a throttling calorimeter becomes necessary."

Generator Details.—It is not necessary to determine the specific gravity of steam coal as a method of checking the uniformity of the supply. The difficulty of securing a fair sample of the run, and the inaccuracies incident to the determination, have made this method of but little value, it being entirely inadequate as compared with the more general custom of a complete analysis. An even more practicable method than such analysis, perhaps, is that of keeping an exact and careful account of results obtained.

As a substitute for the usual steam-nozzle under the grates of the generator, an ordinary malleable **T** fitting may be used, the steam-connection being in the side of the fitting. This has the advantage of acting in a small way as a steam-separator, the incoming steam impinging against the side of the **T** and the condensation or drip falling through the lower opening.

The general results of the modern water-gas generator (U.G.I. apparatus) indicate a consumption of from 30 to 32 lbs. of water per 1000 cu. ft. of gas made. Of this steam only about 50% is actually converted into gas, or, in other words, only about 15 to 16 pounds of steam per thousand feet of gas is dissociated, entailing a loss in net efficiency of from 2 to 3 lbs. of boiler fuel, to say nothing of the generator fuel wasted and " killed." The proportion of steam decomposed, says Mr. Norris, during the early part of the run, is much larger than during the last few minutes, and this seems to point towards desirability of shorter runs, and possibly a more closely regulated admission of steam, instead of following the usual custom of admitting steam at a constant rate throughout the entire run. In addition to this, as has been before mentioned, the make of CO_2 is in inverse ratio to the steam dissociated. The matter of short runs may be carried to an extreme, making the regulation of generator heat difficult and reducing the gross production of the machine per hour materially. The quantity of steam used in the engine operating the blower of a water-gas set is variously estimated at from 15 to 30 lbs. per 1000 cu. ft. per hour.

The amount of water necessary for boiler evaporation, steam for exhausters, fan-engines, oil-pumps, etc., will average about 5 to 6 lbs. per 1000 cu. ft. of gas manufactured. The average amount of boiler fuel necessary to convert this water into steam will average, perhaps, 1.5 lbs. of coal per boiler per horse-power hour.

The boiler installations in a water-gas plant should never exceed the minimum of 2.5 h.p. per 1000 cu. ft. of make per hour, 3 h.p. being a safer factor for installation. In small works there should always be in reserve one boiler; in large works the proportion-

ate reserve of one boiler in five should be maintained. A. S. Miller says that the consumption of steam in his experiments equalled 67.34 lbs. per 1000 cu. ft. of gas manufactured. This will not allow for steam used in heating.

In steam-piping for engines, where bends are used the fitting at joints should be done with a slight stress upon the cold pipe. No actual rule for this can be stated except as determined practically by any expert fitter. When the pipe becomes hot this strain is removed by expansion and leaves it more ready to receive the vibration to which it is subjected. Good fitting with the best material obtainable is invariably economy in the end. Steel flanges welded to the pipe and pulled up with intervening copper gaskets make the tightest joint. Where high-pressure steam is used and the work can be accomplished without a drop of pressure of, say, 4%, it is good practice to run from the boiler (if near at hand) a steam-pipe of one or two sizes smaller than the inlet or throttle valve of the engine. This pipe should be increased to full size within a few feet of the throttle, which serves the dual purpose of having the full supply of steam close at hand, to meet the admission stroke and also to cushion the kick or recoil of the steam due to the closing of the valve at the point of cut-off.

Generator Operation.—A sight-cock is of unquestionable advantage when placed on the coaling-valve of the generator, in that it may enable the gas-maker to watch the condition of his fire without opening the valve. Many superintendents use this sight-cock as a test for "excess steam" on the generator, such being denoted by moisture on the inside of the eye-glass during the run.

In letting down or putting out of operation a set, the best practice dictates that the generator lid, or coaling-valve, be left closed. The clinkering-doors are, however, left slightly ajar, a slight draught should be left on the carburetter through the blast-valve (the blower being shut down), and the top sight-cock on the carburetter left open, as is also, of course, the stack-valve on the superheater.

It is a common practice on machines with reversing steam connections to make every third run a down-run, except that one preceding and the one succeeding the coaling period, when the down-run should always be omitted.

Generators should be clinkered and thoroughly cleaned at least twice every 24 hours. In this operation the machine should be let down, the coaling-valve or lid opened, the clinkering and ash doors also being opened or removed; the fire should then be barred down thoroughly and all lumps of clinker and ash carefully removed. This clinker, if allowed to remain, is not only inert and wasteful

of heating space, but it prevents the blast from proper circulation and has a remarkable condensing effect upon the steam. It tends to chill the fire and prevents diffusion of both air and steam throughout the generator area.

For the elimination of carbon deposits on the checker brick of the carburetter and superheater, Mr. R. H. Sterling of Watsonville, Cal., suggests the burning of zinc in the generator, a process which has served him most successfully.

To reduce the cost of what would otherwise be a very expensive process, the zinc parts of old dry-cell batteries, spent electrodes, scrap zinc, etc., are used; such being obtainable from the telephone and telegraph companies, junk yards, tinners, etc., at a nominal cost. This zinc is thrown into the generators with the fuel and burned, having a tendency to remove the carbon deposits as aforesaid.

The linings of a water-gas generator should, in the case of a good quality of material and an average grade of coke or anthracite coal, last at least three years; the period, however, is apt to be somewhat shorter with coke than coal, by reason of its rapid variation of temperature and intensity of heat; moreover, should either this coke or coal be high in ash or have a marked tendency to clinker, the life of the linings may be reduced to two years.

The life of these linings is also materially affected by the care of handling, heats of "green sets" should of course be brought up slowly, sets should not be "forced," etc.; the necessity of careful operating conditions being intensified in the case of the checker brick, which under the use of average quality gas-oil should last "the rise" of a year, while other conditions of operation may reduce their service to half that period.

It is the belief of the writer that the most disastrous element in the operation of either linings or checker are long daily "stand-bys," wherein the temperatures of the apparatus have time to greatly vary. This fact will also be observed in the case of coal-gas benches, which frequently vary in life from 5 years to 3 years, according to the nature of their service.

Generator Fuels Compared.—Anthracite coal contains less ash than gas-coke and will, therefore, make less clinker. Since it is much denser than coke, a given generator volume will hold a much greater weight of coal fuel and it will neither heat up nor lose its heat as rapidly as coke. Therefore when coal is used longer runs and blows or blasts should be made, as this increases the make or gas production of the machine per hour by the difference in time required for the opening and closing of valves in putting on and taking off runs and blows on the apparatus; this time is materially increased in the use of coke by the fuel-charging

period, which occurs much more frequently in the use of coke than of coal.

As an advantage, however, on the side of coke, it presents to the action of the blast and to the steam a much larger surface than does anthracite coal, owing to its porous nature. The irregular form and roughness of the surface of the individual pieces of coke keep the fuel-bed in a condition favorable to the general and intimate contact of both blast and steam with the carbon of the fuel. The heat can therefore be gotten up quickly, and the gas made at a rapid rate during the shorter run and, with quick workmen, the increase of time required for handling the valves, owing to the shortness of the blow and run, is not of great importance. It is necessary when using gas-coke to be very careful not to prolong either the blows or runs, for, owing to the rapidity with which the coke is consumed, any over-blowing largely increases the fuel account, while any extra length of run increases the amount of carbonic acid in the gas very rapidly, since the fire cools off quickly.

It has been the experience of the writer that coke is most advantageous when used in sets too small to have reverse steam connections, as the coke revivifies more rapidly and presents a larger and fresher surface to the action of the steam. It is also less apt to form into pits and blast-holes, through which the steam in the generator may pass undecomposed.

In general it is probable that fair results as to the quantity of fuel per 1000 cu. ft. of gas manufactured and the quality of the gas made can be secured more readily from coal than from gas-coke, especially when large machines are used.

Furnace- or oven-coke, unless it is made from carefully washed coal, or coal that is originally free from ash, is apt to contain more ash than gas-coke and to give trouble from clinker. It does not possess the density of anthracite coal, nor is it as porous as gas-coke. The 48-hour coke makes a much better generator fuel than the 72-hour hard coke. Opinions as to the relative values of these cokes, however, differ. There is much more to do with the proper handling of these fuels than with the little differences which exist between them, for even slight differences in the price or local conditions are sufficient to turn the advantage in favor of one or the other.

When anthracite coal is used, the trustees of the Educational Class of the American Gaslight Association suggest as follows: "The size of anthracite that is usually considered available for generator fuel is either 'steamboat,' consisting of pieces that will pass through a screen with 4- to 7-in. mesh (the smaller pieces having been screened out); or 'broken,' consisting of pieces that would pass through a 4-in.-square mesh and over a 2¾-in. mesh;

or 'egg,' consisting of pieces that would pass through a 2¼- to 2¾-in. mesh and over a 1⅞-in. mesh. Of these sizes that known as 'broken' has been found to give the best results for generator use, though in many large generators (those over 8 ft. in diameter) steamboat size would be better. The advantages possessed by 'broken' coal are that the lumps are sufficiently large to maintain the bulk of the fire in an open state, which affords the ready passage to the air in blasting and the steam when making gas, and yet are small enough to present a large surface of carbon to be acted upon by the oxygen, and it is thus possible to secure the proper combination of the greater portion of both oxygen and carbon in each case. Smaller coal affords a larger coal surface, but at the same time forms a large compact mass in the center of the generator through which the air and steam cannot pass readily. They therefore pass only through that portion of the area of the generator which lies between the outside walls and this compact mass in the center. The larger-sized coal affords a freer fire with much less total surface, and is also much harder to handle.

"In his paper on the subject, C. R. Collins states that the inactive portion of the fire which is due to the compacting of the coal in the center of the generator, where the lumps can fit each other more perfectly than they can in the space next to the walls, "varies with the diameter (of the generator) and with the size of the coal; thus in a particular generator 'egg' coal renders about 30% of the fire partially inactive, the bulk of the work being done in the outer parts representing 70% of the fuel; in the same way 'broken' coal affects about 15% of the fuel-bed, while 'steamboat' coal leaves a practically free fire. . . . 'Steamboat' coal presents approximately 7 sq. ft. of surface for each cubic foot of generator space. 'Broken' coal, 10 sq. ft. of surface per cubic foot of space; and 'egg' coal, 22 sq. ft. of surface per cubic foot of space. These figures are for selected coal of the standard size in each case. In practice the 'steamboat' coal will have some broken coal in it, and the 'broken' some 'egg,' and so on, and the presence of this smaller coal will increase the size of the inactive portion of the fire as well as the amount of average surface presented to the steam. It is important, no matter what size is being used, that the smaller pieces and slack should be screened out and not used in the generator, the coal used being kept as nearly as possible to the size of the selected standard."

What has been said with regard to anthracite coal also applies to coke. When oven coke is used the large pieces in which it comes from the oven should be broken up to a size corresponding to "broken" coal (i.e., pieces which pass through a 4-in. mesh and over a 2¾-in. mesh), before the coke is charged into the generator.

[illegible]

[illegible]

[illegible] in the manufacture of a more [illegible] upon these [illegible].

[illegible] of the coal, in any great [illegible] finely [illegible] a high percentage of sul[illegible] and freshly mined coal are [illegible].

Carbon Dioxide. This gas is due to incomplete reduction of the CO_2 first formed to CO by the upper layers of incandescent carbon, or to that remaining in the apparatus after blasting. As the temperature of the fuel falls the proportion increases, as shown in the following table:

CARBON DIOXIDE IN WATER-GAS DURING A FIVE-MINUTE RUN.

Minutes Ended.	Butterfield. Per Cent.	O'Connor. Per Cent.
1	0.3	0.5
2	0.6	1.5
3	1.4	4.1
4	2.6	6.2
5	4.2	7.9

The proportion of CO_2 is seen to increase with the length run.

CO_2 in water-gas varies under normal conditions from 1 to 5 per cent, but only 3 per cent should be permitted in good practice.

O'Connor's analysis of American water-gas is as follows:

Constituents.	Per Cent.
CO_2	3.5
CO	43.4
H	51.8
N	1.3

Water-gas of itself has practically no illuminating power, having a faint bluish color.

When air is forced through red-hot coke, 1 lb. of carbon, burning to CO, liberates 4500 B.t.u.; but if burned to CO_2 it liberates 14,500 B.t.u. If there be sufficient quantity of carbon for the CO_2 to pass through, it is decomposed with the absorption of 10,000 B.t.u. Since 1 lb. of C requires 1.25 lbs. of O to form CO, it produces 2.25 lbs. of CO. The quantity of air containing 1.25 lbs. of O would contain 4.5 lbs. of N.

The minimum temperature for the formation of pure water-gas is 1800° F. A lesser heat would mean imperfect combination of the C and O and result in the production of CO_2.

Too little attention is generally given to the maintenance of uniform heats in the generator and to the keeping down of the percentage of CO_2. Some idea as to the detrimental effect of this compound will be given by the following approximate table:

EFFECT OF CARBON DIOXIDE ON THE CANDLE POWER OF GAS.

2.5%	CO_2	causes	a	loss	of	9%	in	candle	power.
5%	"	"	"	"	"	20%	"	"	"
10%	"	"	"	"	"	40%	"	"	"
20%	"	"	"	"	"	75%	"	"	"
30%	"	"	"	"	"	90%	"	"	"
58%	"	"	"	"	"	100%	"	"	"

Carbon Dioxide Analysis: Description.—"As the amount of carbonic acid in the water-gas depends largely on whether the apparatus is properly handled or not, and as an excess of carbonic acid very seriously affects the illuminating power of the gas, it is convenient to have an apparatus by which the percentage of carbonic acid can be quickly and easily ascertained at any time. The fact that carbonic acid is readily absorbed by caustic potash is taken advantage of as follows: A solution of about 1 part by

weight of potash to 3 parts by weight of water is prepared. The absorption and measuring apparatus shown in Fig. 5 is placed in a convenient position and the absorption pipette is filled with the potash solution. This pipette is best filled when made with small rolls of iron-wire gauze, as the absorbing surface is thus much increased. One branch of the three-way cock at the top of the measuring burette is connected by the capillary glass tube with the pipette. The joints are made of rubber tubing. The measuring-burette is made to hold 100 cubic centimeters, and is graduated to read to 0.2 centimeter. A large glass tube, stopped at each end

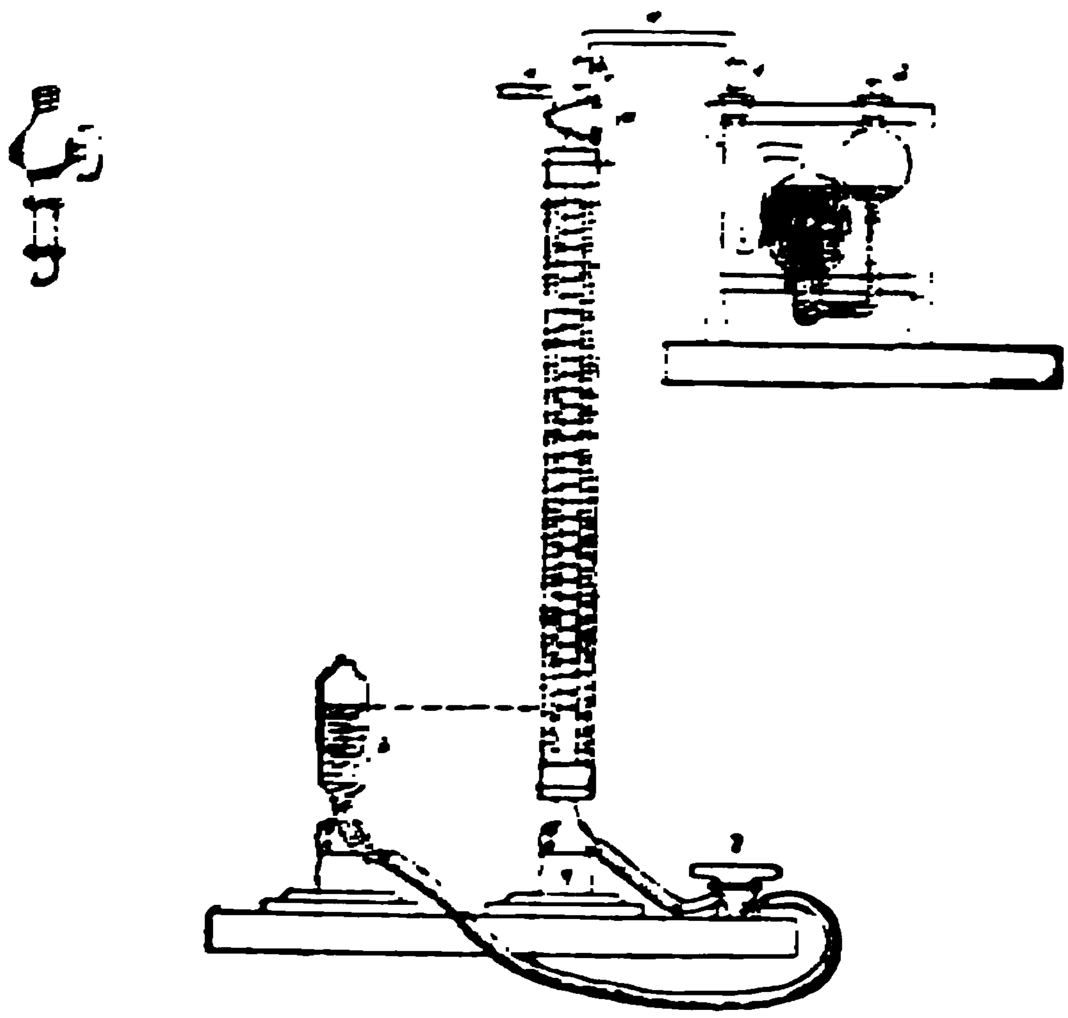

FIG. 5.—Carbonic-acid Gas Apparatus.

with rubber plugs, is placed outside the burette. The space between the burette and the outside is filled with water, forming a water-jacket, which maintains the gas at an even temperature when in the burette. A leveling-tube is connected by a long rubber tube with the bottom of the burette. This bulb is filled with water, preferably distilled, which has been saturated with gas by allowing a small stream of gas to bubble through it.

Operation.—" Open lower stop-cock 1 and turn three-way stop-cock (*a*) so that the burette is open to pipette; then, by lowering the level-bulb *b*, draw the potash solution up the capillary tube to the point *e*, just before the capillary turns down, and close the stop-cock *a*. Leaving lower stop-cock open, turn stop-cock *a* until the

capillary tube *c* is open to the burette, and then, by raising the level bulb *b*, fill burette completely full of water. Close stop-cock 1. Now attach the rubber tube to the gas supply and allow gas to flow through the tube for a moment to displace air; then, with gas still flowing, attach free end of tube to capillary *c*. Open lower stop-cock 1, and then close stop-cock *a* and detach rubber tube. After 3 minutes bring the level of the liquid in the burette exactly to 100 c.c. merely by raising or lowering the level-bulb and close lower stop-cook 1. Open stop-cock *a* to capillary *c* for a moment in order to allow surplus gas to escape. There will be exactly 100 c.c. of gas in the burette, measured under atmospheric pressure. Now open stop-cock *a* to the pipette and force gas over to the pipette by raising the level-bulb, draw gas back into the burette immediately, letting the potash solution follow up the capillary tube to the point *e* as before, and close stop-cock *a*. After 3 minutes, by raising or lowering the level-bulb *b*, bring the water in burette and level-tube to the same level and close stop-cock 1. Note the point at which the water now stands in the burette, and the difference between this reading and the original amount taken will be the carbonic-acid gas absorbed.

"The glass stop-cocks of the apparatus should be kept greased with glycerine, as otherwise they may stick and break when an attempt is made to turn them. A glass cock that has stuck can usually be loosened by the application of a cloth wet with hot water. In order to prevent the absorption of carbonic acid from the atmosphere, the open ends of both level-bulb and pipette should be plugged when the apparatus is not in use. Where unpurified gas is to be tested, the sulphureted hydrogen should be removed by passing the gas through a small oxide purifier before it is drawn into the burette. The solution of caustic potash in the pipette will last five or six months before it must be removed. This method of absorption is the base of all the usual forms of gas analysis, different chemicals being used to replace the caustic potash and absorb the different components of the gas to be analyzed."

Generator Lining.—There should be a double lining in the generator, for that portion extending from just below the level of the grate-bars to a point, say, 5 ft. above these bars, which will be found most economical, for the reason that on this section is the greatest wear and tear, both from heat and clinkering, and this section can be renewed when necessary without disturbing the remainder of the lining.

The rest of the lining may be made of single courses of blocks having the desired thickness, which is desirable, inasmuch as these courses require no support when the inner lining is renewed underneath. Inasmuch as the wear of this last-named section is incon-

siderable, some saving in time and labor is effected by using the full-depth blocks.

Rapid degeneration of generator linings usually indicates either excessive blast pressure, too lengthy blasts, or an insufficiency of blast. In the latter case the blast pressure is not sufficient in its velocity to carry the products of primary combustion over into the other retorts, where secondary combustion of the blast gases should take place. Hence both primary and secondary combustion take place in the generator alone.

Repairing Cements.—It is occasionally necessary to patch the fire-brick in the generator around the mouth or throughout the lining, and for this a compound of salt, sal-ammoniac, fire-clay, and finely powdered fire-brick is a good cement, as is also a composition of iron filings 100 parts, fire-clay 50 parts, common salt 10 parts, and quartz sand or pounded fire-brick 20 parts. For attaching iron and stone or cement, a good composition is fine iron filings 10 parts, plaster of Paris 10 parts, sal-ammoniac $\frac{1}{2}$ part. Fireproof cement for iron pipes consists of wrought-iron filings 45 parts, fire-clay 20 parts, brick-clay 15 parts, common salt 8 parts. As a cement for filling in faults in iron castings: Iron filings free from rust 10 parts, sulphur $\frac{1}{2}$ part, sal-ammoniac 0.8 part, mixed with water to a thick paste and rammed into the cavity. The part to be treated should be previously wiped with ammonia to free it from grease. The old cement commonly used for joining retorts to mouthpieces was $\frac{3}{4}$ part by weight of fire-clay, $\frac{1}{4}$ part by weight of iron borings, mixed with ammonia water.

It is well to have on hand for emergencies a can of Tucker's cement. This cement is of especial use in making temporary patches on blast-pipes, gas-pipes, valves, etc., it being used to advantage when wrapped with strong muslin. It is peculiarly good in temporarily repairing reversing-valves between the generator and carburetter of the apparatus, which are invariably a subject for the "first aid to the injured," as they are but rarely sufficiently water-jacketed.

Blast.—Under date of December 21, 1903, D. J. Collins said with regard to the blast pressure to be maintained in the generator of water-gas sets: "With the use of anthracite coal as generator fuel you should maintain a blast pressure under the generator equal to a water volume of 15 in. to 18 in., and with coke from 12 in. to 15 in. The same pressure applies to all sizes of apparatus. The lower pressure with coke is made necessary because the coke is so much lighter and has so many more open spaces in it that the blast pressure should correspond with the conditions met."

The blast on both generator and carburetter should be constant in its pressure, and the blast line should be thoroughly ven-

tilated. This is necessary to prevent the accumulation of dust, oil, or gas in the blast line during the run, or in the pockets of the valves immediately connecting the machines, and which would occasion an explosion at the opening of the valves and starting up of the blast. This is especially needful in the instance of machines having reverse steam connections.

Safety Devices.—All employees about the works should be taught the location of all valves, steam, water, and gas, which should be labeled as to direction of rotation, and should be especially drilled in the routine of their duty in case of fire. There should be near the generator and at convenient points about the works (especially in the purifying room) standard 2½-inch water-outlets, with suitable fire-hose attached and neatly coiled on racks ready for instant use. This hose should preferably be linen and unlined, inasmuch as lined hose, especially rubber, is damaged and of short life by reason of the heat about the works.

One of the most frequent occasions for delay and shut-down in water-gas manufacture is due to explosion in the blast-pipe or of difficulties with the blower. It is strongly advisable to have inserted in each line of blast-pipe a **T** equal in diameter to the main line. On this **T** should be a cap fitted into the **T** and wrapped

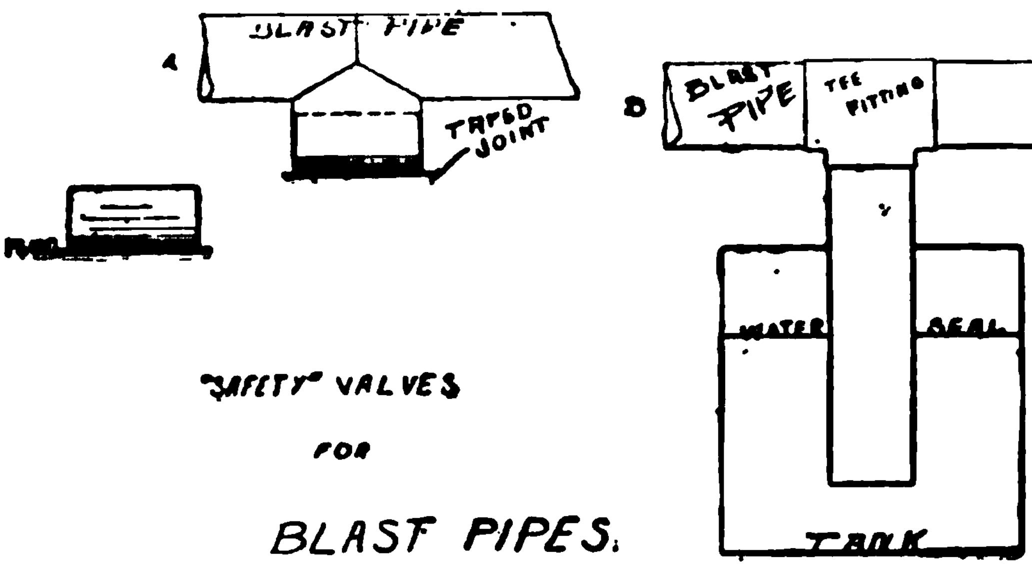

FIG. 6.—Safety Blow-off Blast-pipe.

with some fabric such as tire-tape or electric insulating tape. This joint should be made to withstand a pressure of not more than one pound, or 27 inches of water, and is designed in case of an explosion to act as a safety-valve upon the blast line.

Fire-brick.—The principal precaution to be taken in laying fire-brick or fire-clay blocks is that the bricks or blocks should be thoroughly wet just before they are laid in place, and that each brick or block should be rubbed into place in such a way as to bring its faces in contact with the faces of adjacent brick or block in the wall, the joints being made as thin as possible, and at the

same time to have the fire-clay cement or mortar fill all the interstices, so as to give a uniform bearing over the whole surface. This is especially important in the case of arches, which should be laid as nearly as possible with the blocks face on face. Small bricks and blocks can be wet by being dipped in water. The surfaces of large blocks should be wet by having water poured on them with a hose. The portion of the work previously laid, and upon which the wet bricks or blocks are to be placed, should also be wet.

To secure thinness of joints those surfaces of the blocks which come together should be smooth, plane surfaces, being dressed to this condition if they do not originally possess it, and the fire-clay mortar should be mixed thin rather than stiff, care being taken that it is not so liquid as to run out of the joint, nor so stiff that any excess will not be squeezed out when the joint is worked into place. If the joints are not made thin the fire-clay will soften and run when subjected to extreme heat, or it will shrink under the action of heat and cause the upper portion of the brickwork to settle.

When it is necessary to cut bricks or blocks, the cut or broken section should never be exposed to the direct action of the fire, the face so exposed being always the one uncut or unbroken.

The qualities desired in fire-bricks or blocks are infusibility, strength, regularity of shape, uniformity of composition and facility of cutting, and the test to be applied to a fire-brick should be such as would determine to what extent it possesses these qualities.

An excellent test for the fire-resisting qualities of fire-brick is to throw a brick into the generator along with the coal or coke and allow it to pass through, taking it out with the generator screenings. Any tendency to fuse or crumble will then be indicated by the condition of this sample.

The degree of infusibility can be determined to a certain extent by an analysis of the material of which the brick is composed. If this analysis shows the presence of about 60% of silica, less than 6% of sequioxide of iron, and not more than 2% to 3% as the total of lime, magnesia, and hydrates of potassium and sodium, the brick probably possesses a high degree of infusibility. If the analysis indicates more than 6% of sesquioxide of iron, or more than 2% to 3% of lime, magnesia, etc., the brick should be rejected; but exposure of the bricks to the action of heat under the conditions to which it will be subjected when used, furnishes the best test of fusibility. In coal-gas works it can be made by placing the brick in the combustion chamber of the generative bench. If when the brick is removed, after being exposed for a week to the heat of the chamber, the edges and corners are found to be sharp and the surfaces show no signs of incipient fusion, the brick may be passed

as a first-rate quality in respect to infusibility. In water-gas plants the space at the bottom of the superheater in which the secondary combustion occurs furnishes a good place for the test, or the passage of a sample brick through the generator together with the fuel.

If the material of which the brick is made is well compressed during manufacture, and the brick is hard-burned, there is little question as to its strength when cold; any defect in material or manufacture is indicated by crumbling or fusing. The degree to which compression has been carried is indicated by the weight of the brick. A fire-brick of regulation size, $9\times4.5\times2\frac{5}{8}$ inches, should weigh in the neighborhood of 7.25 to 7.5 lbs. A well-burned brick should have a reddish tinge. A well-compressed and well-burned brick should give a ringing sound when struck with a hammer. It is especially necessary that bricks in the lining of retort-benches and water-gas generators should be hard, since they are subjected to a great deal of abrasions from the fuel and the clinkering-bar, so that to this work hardness and strength are really of as much importance as infusibility. In the combustion chamber, as in the carburetter and superheater, infusibility is the more important quality, since the material used is not exposed to any wear and tear except that arising from the effects of the heat, and it may thus frequently happen that the same brick is not suitable for use both in the furnace or combustion chamber and in the two other chambers. An examination of the exterior of the brick is all that is necessary to determine whether or not it possesses regularity of shape.

Uniformity of composition can be ascertained by breaking the brick and examining the surfaces of the fracture. This should present a compact and uniform appearance, though not necessarily a close and fine texture. In fact some authorities prefer a coarse texture, as possessing greater infusibility. Uniformity of composition is also indicated by the giving out of a clear ringing sound when the brick is struck a sharp blow with a hammer or trowel edge.

Facility of cutting is important only as reducing the cost of labor and the amount of waste during the operation of laying the brick, and, while desirable if it can be secured without sacrificing the more important qualities, cannot be considered as equivalent to any of the other specified qualities. (The above information is credited to the trustees of the gas educational class of the American Gaslight Association.)

It will be observed in the study of fire-clays (clays having a fusing-point above 2700°) that the coarser-grained fire-brick stand heat better than the finer texture, although they stand less well

the action of molten metal. In their order they have been classed as:

No. 1. Highly refractory:
- *a.* Flint fire-clay;
- *b.* Plastic fire-clay.

No. 2. Moderately refractory:
- *a.* No. 2 "A" fire-clay;
- *b.* Stoneware clay;
- *c.* Sewer-pipe clay.

The method of manufacturing fire-brick, as well as the material of which they are made, has undoubtedly much to do with their degree of excellence. For example: All things being equal, the heat conductivity of the brick would vary in accordance with the pressure which was applied to it during its manufacture, the air spaces between its particles, or the porosity of the brick, decreasing its conductivity.

The size of a water-gas generator is determined by most engineers by an allowance of one square foot of grate surface for each 30,000 cu. ft. of gas made in 24 hours; the fuel-bed to be at least 8 to 9 ft. deep.

The data given by Alfred Wolff of New York City are very often used for computing the amount of heat passing through fire-brick walls. A gives the thickness of the wall in inches, and B gives the corresponding number of B passing through the walls per square foot of area per hour for each degree difference of temperature (Fahrenheit) between the two sides:

A........	44	8	12	16	18	20	24	28	32	36	40
B........	0.43	0.37	0.32	0.28	0.26	0.25	0.24	0.22	0.21	0.18	0.18

Hornby says, under Analyses of Fire-brick and Clay, pp. 194 to 199: A refractory fire-clay will contain nearly pure hydrated silicate of alumina. The more alumina there is in proportion to the silica the more infusible will be the clay. The composition of different fire-clays necessarily varies, however; they contain:

Silica..........................	59 to 96 per cent.
Alumina......................	2 to 36 " "
Oxide of iron..................	2 to 5 " "

and a very small percentage of lime, magnesia, potash, and soda. The fire-resisting properties of the clay depend chiefly upon the relative proportion of these constituents. If oxide of iron or alkalies are present in large proportion they act as a flux and result in fusion. The clay is then no longer refractory.

Fire-clay Analysis.—The following is the method of analysis: The quantity of the substance (either fire-clay or fire-brick) is reduced to an impalpable powder in an agate mortar and placed in a stoppered weighing-tube. About 2 grams of this sample are dried in a platinum crucible or dish at a temperature of about 100° C. (212° F.) until the weight is constant; the loss in weight gives the moisture. In the case of fire-clay it is then ignited, at first gently and then strongly and for a tolerably long time. The loss of weight corresponds to the water in combination together with the organic and volatile constituents of the clay, if such are present.

Then 1.5 grams of the powdered sample are weighed accurately into a platinum crucible and about four times this weight added of a fusion mixture, consisting of sodium and potassium carbonates. The whole is intimately mixed by means of a smooth, rounded, glass rod. It will be found convenient to add the fusion mixture by small portions at a time, since in this way a more thorough mixture is obtained. The mixture should only half fill the crucible.

The lid is then placed on the crucible and the latter gently heated over the Bunsen flame; the temperature is gradually increased, care being taken that no loss occurs through boiling over due to the evolution of CO_2. When the mass is fused the crucible is transferred to the blowpipe flame, and the whole is kept at a bright red heat until bubbling ceases and the fused mass becomes tranquil. The flame is then removed and the crucible is allowed to cool just below redness, when it is placed on a cold surface, such as a clean block of iron, in order to assist it in cooling rapidly. When cold the crucible and its contents are placed in a deep evaporating dish or in a shallow beaker; this is covered with a large watch-glass and tolerably strong hydrochloric acid added to the contents, which should be gently agitated after each addition of the acid and kept covered during the operation. When effervescence has ceased and the crucible is free from all adherent solid, remove the crucible by means of the crucible tongs, carefully rinsing off any adhering liquid, by means of the jet from the washbottle, into the main portion of the liquid. On treating the fused mass with HCl, as above described, most of the SiO_2 will separate out as a gelatinous mass.

If any gritty particles are felt, on stirring the bottom of the vessel with a glass rod, the fusion is imperfect. This is generally due to the original substance not having been powdered sufficiently finely. In this event it is usually more satisfactory to make a fresh fusion, taking care that no coarse particles are present in the portion of the sample used for the new fusion.

a. Estimation of the Silica.—The liquid containing the gelat-

inous silica is now transferred (if necessary) to an evaporating basin, preferably of platinum and evaporated to dryness upon a water-bath. When the contents of the basin become pasty they should be continually stirred with a rounded glass rod to prevent the formation of lumps. When all the liquid has been driven off, the contents of the dish should then be in the state of fine powder. In order to expel the last trace of HCl the dish should now be placed upon a sand-bath and heated with a small Bunsen flame until no moisture is deposited on a cold clock-glass when placed upon the dish for a few seconds. The dish is then allowed to cool and its contents are moistened with strong HCl. It is then heated on a water-bath for about half an hour, a small quantity of hydrochloric acid being occasionally added with stirring. Hot distilled water is now added and the silica is filtered off and is washed free from dissolved chlorides. The precipitate is ignited apart from the filter, the precipitate being transferred to the platinum crucible cautiously, since it consists of a very light powder which is easily blown away. The lid is placed on the crucible and the latter heated, exceedingly gently at first and the temperature raised very gradually, or the escaping steam will carry some of the fine powder away with it. The crucible is finally raised to a full red heat over the Bunsen flame and the silica weighed.

b. Estimation of Al_2O_3 and Fe_2O_3.—The filtrate from the SiO_2 determination is mixed with NH_4Cl solution and then with NH_4OH in slight excess, the hydrates of iron and aluminium depositing as a precipitate. This precipitate is washed, and dissolved upon the filter in hot diluted hydrochloric acid, and the solution allowed to flow into a nickel or porcelain dish containing about 50 c.c. of pure strong KOH solution. Wash out the acid which remains in the filter-paper with a small quantity of distilled water, allow these washings to also run into the dish and boil the contents of the latter for a few minutes. The iron will be precipitated as ferric hydrate, while the hydrate of aluminium will remain in solution.

The iron precipitate is filtered out, again dissolved in HCl and reprecipitated by NH_4OH in order to free the ferric hydrate from KOH. It is then filtered, washed, ignited apart from the filter at a red heat and weighed as Fe_2O_3. The filtrate of aluminium hydrate in the KOH solution is treated with a slight excess of strong HCl, and then with a very slight excess of NH_4OH. The precipitate is then filtered off, washed, dried, ignited, and weighed as Al_2O_3.

Another method of separation after weighing the mixed hydrates of iron and aluminium is to dissolve them in $KHSO_4$ and about 5 c.c. of H_2SO_4; add about 1 gram hyposulphite of soda,

boil and titrate the solution with a 1 per cent solution of normal bichromate of potash; this will give the amount of iron.

c. Estimation of Calcium.—If the volume of the filtrate from the iron and alumina precipitate is very large, evaporate it down to a convenient bulk, add a little NH_4OH if not already alkaline and then a slight excess of ammonium oxalate. Allow the liquid to stand and the precipitate to settle, filter off, ignite and weigh the precipitate as CaO.

d. Estimation of the Magnesium.—Evaporate the filtrate and washings from the calcium oxalate precipitate to dryness, ignite the residue and treat it with a little strong HCl; add water and filter if necessary. To the clear solution add ammonium hydrate in moderate excess, and then an excess of sodium hydrogen phosphate solution. Allow the liquid to stand for a few hours, or shake it vigorously in a stoppered bottle, filter off, wash the precipitate with dilute ammonium hydrate solution, then ignite it and weigh the magnesium as $Mg_2P_2O_7$.

e. Estimation of the Alkali Metals.—Since sodium and potassium carbonates have been employed in the fusion, the alkali metals cannot be estimated in the filtrate from the magnesium determination. A separate portion of the fire-clay sample is accordingly used for their determination. Lawrence Smith's method for the determination of the alkali metals will be found the most convenient. The following is the mode of procedure:

Weigh out accurately about 1.5 grams of the finely powdered substance into a platinum crucible, intimately mix this with a mixture of 1.5 grams of pure recrystallized ammonium chloride and 9 grams of pure calcium carbonate. Then either heat the crucible to bright redness for an hour over a good Bunsen or blowpipe flame, or preferably as follows:

Place the platinum crucible in a clay crucible containing a little calcined magnesia or lime at the bottom and round the sides, and heat the clay crucible in a gas-furnace which is capable of maintaining it at a bright red heat. When the crucible has been heated for an hour, allow it to cool, place the platinum crucible and its contents in hot water in a covered platinum or porcelain dish and boil for a time.

This procedure will dissolve out the alkaline chlorides together with some calcium hydrate. Filter and mix the filtrate with NH_4OH and $(NH_4)_2CO_3$ solutions in excess and with a few drops of ammonium oxalate solution. Allow the liquid to stand, filter into a platinum or porcelain dish, evaporate the filtrate to dryness and heat the residue just below redness, but sufficiently strongly to drive off the ammoniacal compounds.

Dissolve the residue in water containing a few drops of NH_4OH and ammonium oxalate solution to precipitate any trace of calcium compounds still in solution; filter, evaporate the filtrate, heating it to redness in a weighed dish after adding a few drops of HCl. Gently ignite the residue and weigh, repeating the ignition until the weight is constant. The weight of the residue thus obtained gives the combined weight of the alkalies as KCl and NaCl.

The residue is then dissolved in water and the potassium chloride is precipitated by platinic chloride in the following manner: To the solution of the residues a few drops of HCl are added, then an excess of platinic chloride solution, the liquid being afterwards evaporated on the water-bath until a semi-solid crystalline mass is obtained. The platinic chloride is seen to be in excess by the supernatant liquid being of an orange color, after the liquid has been concentrated to a small bulk. When it is certain that there is an excess of platinic chloride, we may then proceed according to either of the following methods:

1. Pour alcohol upon the mass, gently shake the liquid round in the dish so as to mix the contents of the same well together, allow the precipitate to settle completely and pour off the liquid through a tarred filter. Repeat these operations twice and finally transfer the undissolved double salt to the filter with the assistance of a small wash-bottle filled with alcohol. Continue washing the precipitate upon the filter with alcohol until the washings are no longer colored. Dry the filter and its contents at 100° and weigh as $2KCl.PtCl_4$.

2. A rather quicker method of treating the precipitated double salt is to wash it with alcohol by decantation until the alcohol is no longer colored, the alcohol being decanted through an untarred filter-paper. Care must be taken that as little as possible of the precipitate is poured off with the alcohol. The double salt, freed from the excess of PtCl, is now washed into a platinum crucible, dried at 100° C. and weighed. The filter, which will contain a little of the double salt, is then incinerated, and the ash is dropped into the crucible and weighed. By deducting from this weight the weight of the filter-ash, the approximate weight of platinum left by ignition is found; this is calculated into double salt and the weight is added to that of the double salt already found in the crucible. If the quantity of precipitate left on the filter is appreciable, the weight of KCl left in the filter-ash, not being allowed for, will introduce an error. The filter in this case should be ignited in a separate crucible, the KCl washed out from the ash by hot water, and the dried residue

weighed. The true weight of the platinum in the ash is thus ascertained and is made use of as mentioned above.

The weight of the sodium chloride in the mixed chlorides of potassium and sodium is then ascertained by difference. The chlorides are finally calculated as K_2O and Na_2O.

CHAPTER II.

THE CARBURETTER.

THE carburetter one may divide into two topics:

1. That pertaining to the brick, and 2. That to the oil, oil-pump and appurtenances.

Brickwork.—Of the first it is difficult to lay down any exact rule, as conditions, the class of oil, and the class of brick used greatly alter the situation. It is perhaps well to have a brick neither too hard nor too soft, one which will not vitrify, fuse, and become brittle under the intense heat, nor yet crumble from being too soft. The ideal brick is one in such a condition that it attains its final hardness only after being subjected to the carburetter heat. Many methods are in vogue as to the laying of brick in the carburetter and the use of "soaps." These ideas, however, are largely a matter of personal preference, as is the practice of "coning" the brick, or bringing the brick up to the oil-spray in a pyramidal form.

The main point, however, lies in close attention and proper treatment of the oil-spray, which should be examined at least every coaling period, if not oftener, and freed from any clogging material or other hindrance to its free action. This item of operation cannot be too forcefully emphasized, as, next to the proper maintenance of an even heat, it presents the greatest opportunity for the gas-maker to economize material.

The bricks of the carburetter should also be examined periodically and replaced as soon as they become carbonized. The life of bricks depends very largely upon the proper handling of carburetter heat, for improper manipulation of this heat on the part of the gas-maker very quickly clogs and carbonizes them. This is especially true in the case of low heat and the crowding of more oil on the machine than it is able to vaporize. These heats are a matter of much discussion and diversity of opinion on the part of gas-makers, the author's best results being obtained by a condition of heat which shows a bright orange just short

of a white tinge at the completion of a blast and a cherry-red at the completion of the run. The run should never be so long nor the quantity of oil turned in sufficient to "kill" the heat of the carburetter and to require relighting at the commencement of the blast.

Regarding the cleaning of checker brick the committee of the American Gaslight Association states as follows:

"The checker bricks of a water-gas apparatus should be removed and cleaned, or renewed, when dirty, crushed, or disintegrated. Checker bricks may become covered with a non-conducting coating of ashes or carbon, or both, making impossible the desired exposure of the oil-vapors to properly heat the brick surfaces. When bricks are coated or saturated with carbon the surface heats rapidly, because the carbon burns, and the gas-maker is deceived by the glowing carbon and believes the bricks to be hotter than they are. It is possible to tell something of the condition of the checker bricks by observation through the sight-cocks provided for the purpose. Other indications of dirty bricks are a falling off in the rate of make per minute and in the oil results. If all the conditions of operating remain unchanged, and the candle power falls materially and stays down, and the make of gas per minute of run is reduced, the checker bricks should be at once examined and, if dirty, cleaned or renewed. Bricks should not be allowed to become so fouled as to make a material reduction in the rate of make. Experience soon teaches an intelligent gas-maker to avoid both the extreme of reduced results and of too frequent cleaning."

Checker-brick Spacing.—The carburetter and superheater shells are not only lined with fire-brick, but are filled with courses of brick with spaces between, so that during the blast these bricks may be heated to the degree required to fix the oil-vapor passing through them during run or gas-making period. The proper spacing of these bricks was the subject of an article published in *Progressive Age* (Oct. 1, 1904, p. 514) by J. A. Perry, in which the relation between size of brick and space between bricks to obtain the best results with both oil and fuel was developed into a formula, as follows, for size of brick $2.5\times4.5\times9$ in.:

$$F=\frac{\pi d^2h}{9}\left(\frac{28x+45}{(2x+5)^2}\right),$$

where F = flame surface of checker brick in vessel after deducting surfaces in contact, in square inches;

d = internal diameter of fire-brick linings of vessels, in inches;

h = height from bottom to top of checker brick, in inches;

x = space between rows in each course of checker brick.

The accompanying curve shows the relation of F to x.

Suppose Q cubic inches of gas pass through the total space between bricks in small interval of time t and $R = \frac{\pi^2 d^4 h^2}{18}$, M is a

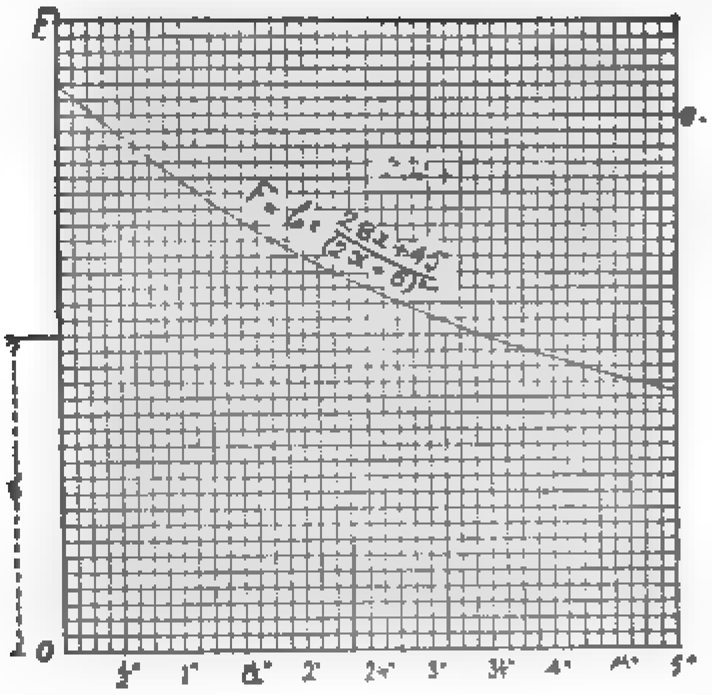

FIG. 7.—Relation of Flame Surface to Spacing.

variable coefficient depending on the temperature and specific heat of gases and brick, and H is the B.t.u. of heat absorbed by the checker brick during the blast in time t, then

$$H = \frac{RMt}{Q}\left(\frac{28x^2+45x}{(2x+5)^3}\right).$$

The first differential coefficient of H with respect to x, when placed equal to zero and solved, will give a minimum value for H. Let

$$Y = \frac{28x^2+45x}{(2x+5)^3};$$

then the value of the first differential which will make it zero is 3.09 inches. The relation of Y to x is shown in Fig. 8.

This figure shows that with a spacing of about 3.1 inches the absorption of heat by the checker brick is a maximum, although there is not much difference between 2.5- to 4-in. spacing evident on the curve. If we call b the time of blast in minutes, r the time of run in minutes, V_1 the volume for gases between brick in one

case and V_2 this volume for some other spacing, G_1 the daily make for one spacing and G_2 the volume by another spacing, then

$$G_2 = G_1\left(\frac{b_1+r_1}{\frac{b_1 V_1}{V_2}+r_1}\right).$$

From this it would seem that 3.1 inches was about the proper spacing for checker brick in the carburetter. The author claims

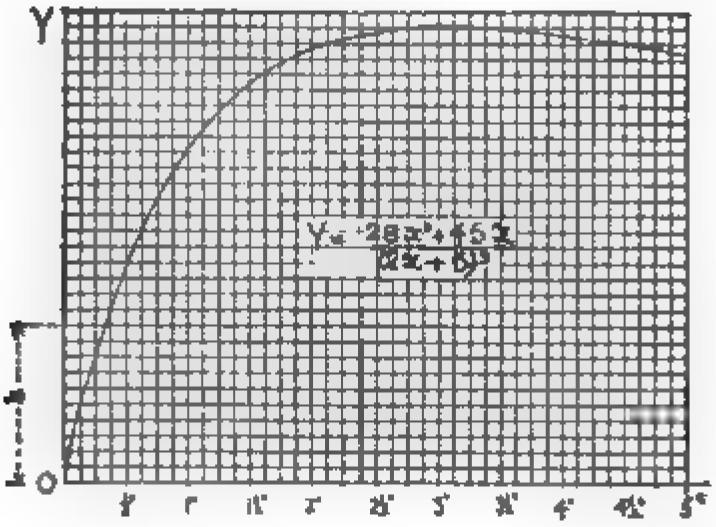

FIG. 8.—Relation of Brick Spacing to Heat Absorption.

for this spacing that it allows a quick blow with high blast, saving of fuel, better retention of heat by carburetter, improved oil yields, and increased output of gas. Close spacing keeps the temperature down, and wide spacing lets it rise. Thus for a 2.5-in. spacing Y is equal to 0.2875 and for a 1.25-in. spacing 0.2371, or a relatively lower heat absorption; the first might be employed in the carburetter and the second in the superheater to keep the temperature down in the latter. However, with small spacing a high blast is essential, and it is difficult to heat the carburetter sufficiently so that its brick should be relatively wide-spaced.

Oil Supply.—Another item concerning which opinion widely differs is the heat at which the oil should be turned into the carburetter, many gas-engineers advocating the practice of vaporizing the oil prior to admission. The claims made for this method are: 1. The saving of fuel due to utilizing the waste heat of the machine during the blast in heating the oil; 2. The saving to the checker brick of the carburetter; 3. The more perfect decomposition of the oil.

The efficacy depends somewhat upon the individual condition

and the character of oil used. In case the method of prior vaporization should be adopted, the easiest plan is to connect in to the pipe-line a return bend-coil (say a 1.5-in. pipe), to be situated in

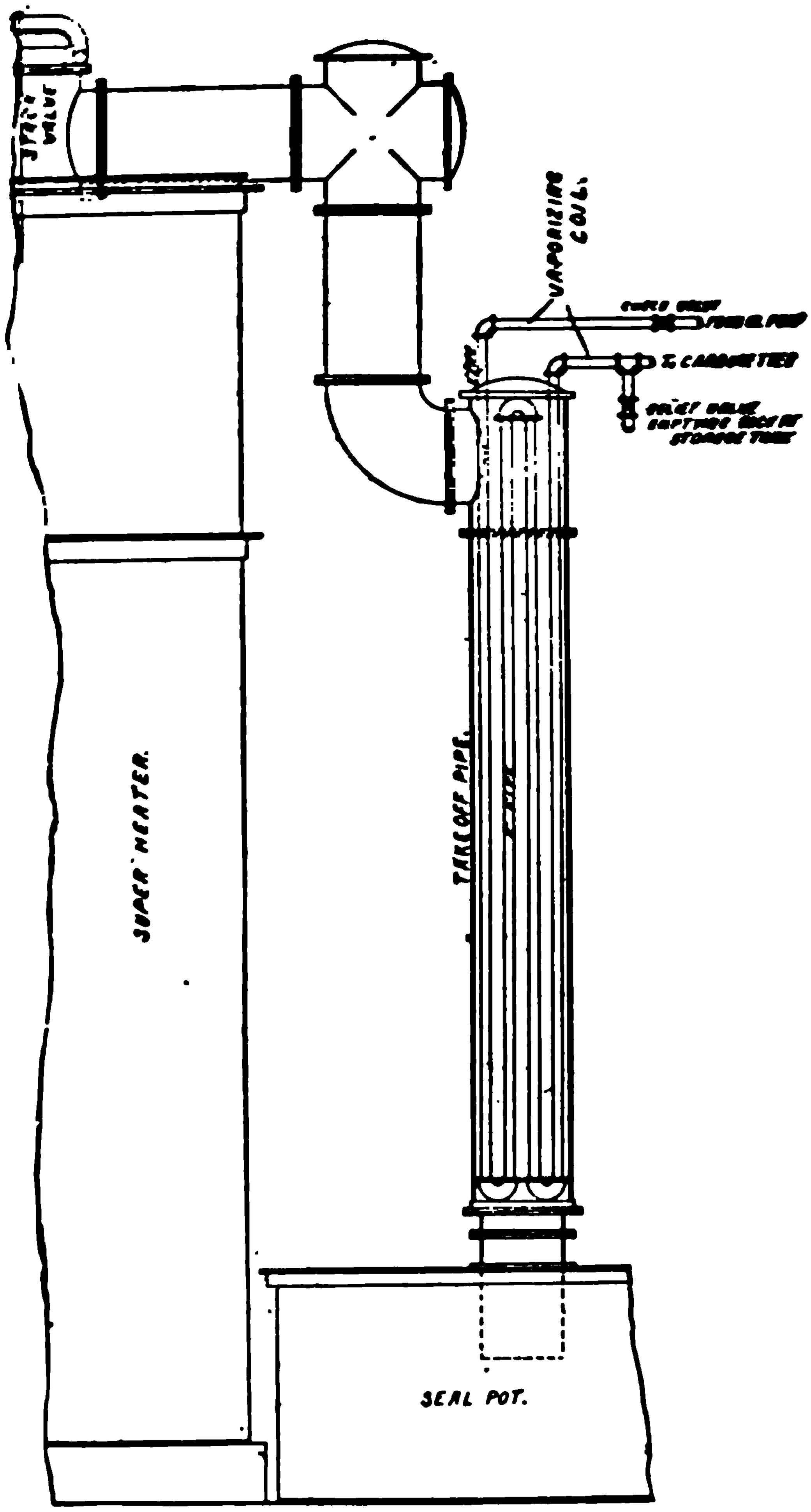

FIG. 9.—Oil Preheater in Take-off Pipe.

the take-off pipe of the superheater (Fig. 9). This coil may be made 10 or 12 ft. long (depending upon the size of the machine) and consist of some 6 or 8 coils, it being possible in this manner to

bring up the oil to a temperature of 700° or 800° F. prior to its admission into the machine. The whole principle is much the same as that of the feed-water heater and economizer in steam-boiler practice. There should be a relief-valve connected in series with this coil and emptying back into the measuring-tank. Between the measuring-tank and the coil there should be a check-valve, as the pressure of the vaporized oil sometimes rises to several hundred pounds per square inch.

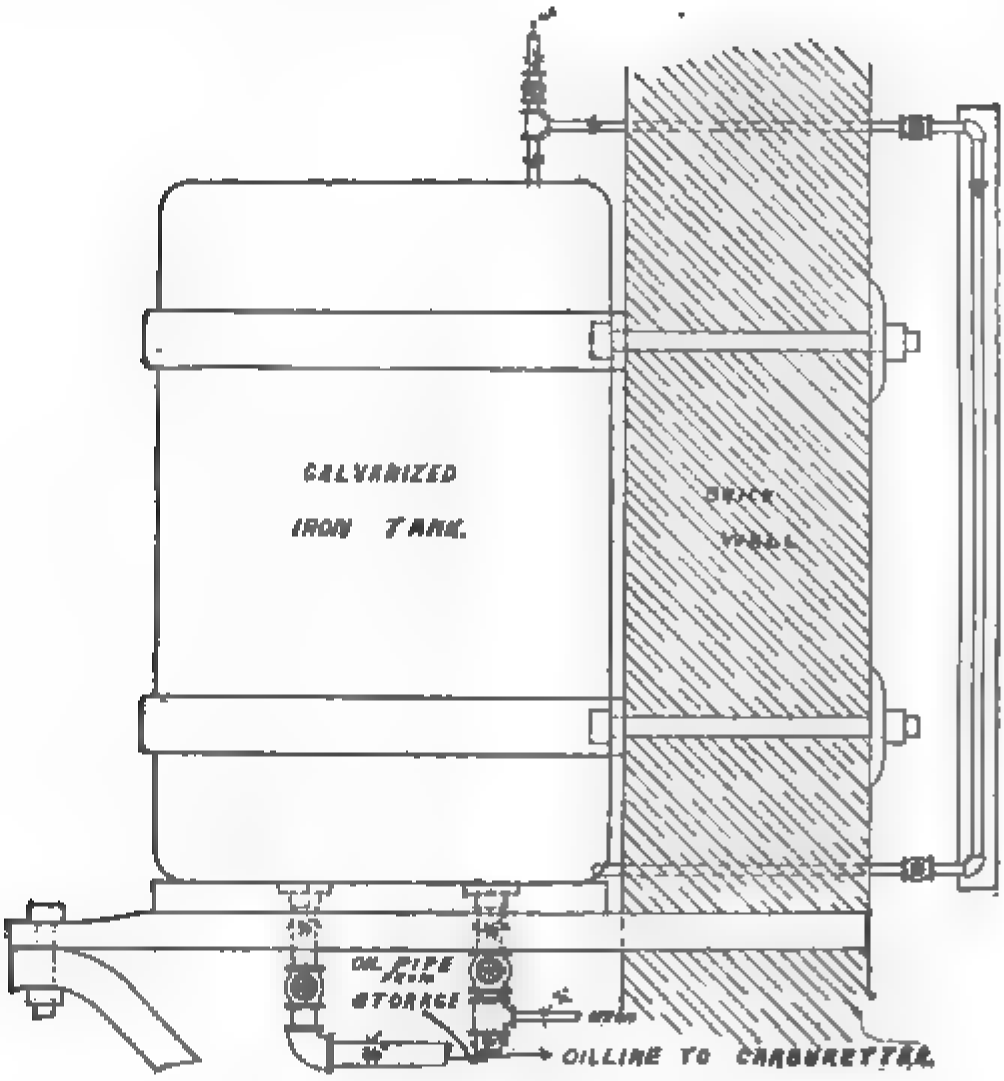

FIG. 10.—Oil-measuring Tank.

Oil-pump.—The oil-pump should be situated below the measuring-tank and before the oil-heater. It should maintain a constant pressure on the carburetter of from 60 to 70 lbs. per sq. in. The piston-rods of this pump and the lining of the cylinders should be of brass to resist the action of the acid in the oil. The writer has found "Vulcabeston" packing especially applicable to oil-pumps. There is but one compound which has ever been successfully used in making tight oil-pipe joints, and it consists in equal parts of white lead, red lead, coach varnish, and dryers.

It will be noticed that the author has referred to a measuring-tank instead of an oil-meter, although either may be used. The tank (Fig. 10) is a simpler device, and may be used to advantage as a check even where the meter is used. The oil is pumped from the storage-tank to a small measuring-tank fitted with a glass gage having a scale calibrated to read in gallons direct. This tank is pumped full, and the connection with the storage-tank is then shut off. It flows by gravity and serves as a head upon the oil-pump, which then forces it into the carburetter. It is at all times accurate and requires none of the frequent adjustment attendant upon oil-meters.

Oil Storage.—It may be well in connection with the carburetter to note the oil-tanks and their convenient arrangement. When a tank-car is received at the company's siding it should be inspected by the superintendent. A sample should be taken therefrom and a hydrometer test made, after which a sample should be placed in a flask and allowed to stratify. As oil and water will form a mechanical mixture due to the churning of the car in motion, this mixture will separate and stratify if left undisturbed for a sufficient length of time. Each works should be supplied with a copy of the Tank Gage Handbook, No. 2,* giving the capacity of every tank-car in use for hauling oil in the United States. It is well to have one tank of at least 10,000 gallons capacity, with a table showing its capacity at various depths of oil. This tank should be connected in series with any other storage-tank which it is most convenient to use, in solid units of 5000, 10,000, or 20,000 gallons each. An exceedingly flexible pipe system should be arranged by which each tank can be connected to the main line or any other tank. In this manner the storage-tank can be used in units, and the measuring-tank for fractional portions in the checking up of the contents of arriving cars. For example, we will assume the arrival of a car containing 8000 gallons of oil. One tank with a capacity of 5000 gallons is connected to the tank-car and filled; the remaining 3000 gallons is then turned into the measuring-tank, thereby enabling the superintendent to exactly check the quantity of oil received.

An oil-car is considered full when the oil level is flush with the top of the tank, where it is joined by the base of the dome. Inasmuch as oil-producing or -shipping companies occasionally bring up, in case a shortage is claimed, the question of temperature, it is well to let down into the car of oil a thermometer and to record its temperature for future reference.

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* This book can be obtained by writing to the Central Traffic Association, The Rookery, Chicago.

As it is usual to have oil-tanks and unloadings occur on or near sidings, where there is a constant passing of locomotives and where there is danger that sparks may fall in and ignite the oil through the open dome of the tank-car, a hood should be provided to screen such openings and at the same time permit the passage of air into the tank-car in order to prevent the tank from becoming air-bound.

There is also, especially during hot weather, a vapor which arises from these oil-tanks, and it is well to put a connection between storage-tanks and the holder in order that the holder pressure may be upon these vapors and at the same time permit the gas the benefit (if any) of the volatile hydrocarbons.

Great care should be taken in examination of the spray or oil-injector of the carburetter. This, as has been suggested, should occur at frequent periods to see that it is in proper working order and that the oil is being equally distributed over the entire surface of the carburetter brick. Rotary sprays have a tendency to clog and become jammed, thereby concentrating the oil upon a limited area of the brick, where it fails to evaporate, is carried off as tar, and fouls the brick, while the unsprayed portions of the carburetter become unduly hot by failure of the cooling influence of the oil; this burns up both oil and brick, or forms naphthalene in such of the hydrocarbon vapors as eventually escape.

In addition to the test-lights used on all water-gas sets, it is well to have one or even two Knott jet photometers connected in series so as to check each other on the inlet of the storage-holder. This photometer should be checked by comparison with the regular bar-photometer at intervals of not more than a week.

Grades of Oil.—Of the gas-oils used for enriching water-gas, the three most common forms are crude oil, known as BS or petroleum, naphtha, and gas-oil. Petroleum is the oil in its crude or native form as it comes from the well. It is a mixture of hydrocarbons, has different chemical compositions, varies in specific gravity and boiling-point, and can be broken up into these various substances by fractional distillation. The chief producing fields for crude oil are the United States, Russia, and Peru. Pennsylvania and Ohio crude varies in specific gravity from 0.80 to 0.85 (water being 1). Its color also varies, the most common being a dark claret color by direct, and a greenish color by reflected, light. Oil commences to distil at 40° C. Some of the qualities of oil which make it suitable for gas-making are as follows: It should be as nearly as possible free from water; the residue, after distillation, should not exceed 1 per cent.; only the last fraction should be of a pronounced dark color; the rapid

blackening of lead-acetate-impregnated paper should not take place until far along in the distillation; under ordinary circumstances the first distillate should be nearly colorless, later becoming an amber or pale straw tint, only the last fraction indicating a decided brown. The flashing-point for this class of oil is usually between 120° and 250° F.

Naphtha is a general term given to those distillates of oil which are given off during fractional distillations of crude oil, between gasoline and lamp-oil; this oil is volatile and very inflammable, its gravity running from 0.67 to 0.74.

What is commercially known as "gas-oil" is a general name given to those distillates between the lamp-oil and lubricating-oil series; this oil has so high a boiling-point and is so heavy as to be useless for illuminating purposes, while it is not sufficiently viscous to be used as a lubricant. As a matter of fact, however, this term covers a multitude of odd distillates, or "waste oil" unfit for other purposes, and as a result, so-called gas-oil varies in color, gravity, and constituents, its average gravity being, perhaps, about 0.85. By reason of these variations in gravity, boiling-point, etc., it requires most careful handling on the part of the gas-maker, and he must constantly vary his heat in compliance with the strata of oil which he is taking from the tank; the manipulation of which requires much judgment and long experience.

Chas. F. Cattell mentions the economical use of 20 per cent. of water-gas tar, with 80 per cent. of oil as a water-gas enricher, the apparatus in use being a six-foot Lowe machine, ordinarily using 20 gallons of oil and a make of from 4300 to 4800 cubic feet of gas per run. Separate tanks and sprays were used for injecting the tar, the tar being admitted to the generator.

Oil Analyses.—Concerning the method of examination for gas-making oils, the following is extracted from Butterfield's excellent treatise on Gas Manufacture:

"The laboratory examination of an oil to determine its fitness for gas-making embodies the operations described hereunder. The specific gravity of the oil and its temperature at the time of taking the specific gravity are ascertained. A hydrometer with an open scale serves for taking the specific gravity if the instrument is known to be correctly calibrated. The scale should be sufficiently open to allow reading accurately to within 0.0005; the thermometer should be in the oil while the reading is being made and be read immediately after the hydrometer. Failing the use of an accurate hydrometer, the specific gravity must be taken in the ordinary way with a specific-gravity bottle, but the high coefficient of expansion of petroleum renders care-

ful and rapid working necessary, and care is requisite to obtain correctly the temperature of the oil at the time of weighing. By either method it is desirable that the specific gravity should be taken at the standard temperature, usually 60° F.; but as this is generally impossible, it should be corrected to that temperature by means of the coefficient of expansion of the oil, which may, in general, be taken at 0.00036 per degree Fahrenheit as an average value for petroleum oils. Oil is frequently bought and sold by weight, which is calculated from its volume and specific gravity, hence the accurate determination of the latter has special importance in many cases.

"The flashing-point of burning oil is determined in England by the apparatus devised by Sir Frederick Abel and adopted as the standard by the Board of Trade. For oils of low flashing-point it is equal or superior to any of the forms of apparatus adopted in other countries. A description of the method of making a determination with it is given with each apparatus, and there will be little divergence in the results obtained by different operators if the directions are implicitly followed. Most oils suitable for retorting have, however, fairly high flashing-points, and the determination can be made with sufficient accuracy in a much simpler apparatus. This consists simply of a cylindrical copper vessel, about 3 inches in diameter and 3 inches deep. The lid overlaps the top of the cylinder, but a flange $\frac{3}{4}$ inch deep attached to it fits within the cylinder and keeps the lid in position. The lid is perforated in two places: one hole is for the insertion of the thermometer held by a perforated cork fitting the orifice; the other is covered by a small lid pivoted to the cylinder cover, so that the opening can be exposed by sliding the lid from it, and can be covered again immediately after each application of the test flame. The oil to be tested fills the cylinder to a height of 2 inches, and the bulb of the thermometer is immersed in the liquid when the cover is in position. Heat is applied to the bottom of the cylinder by means of an Argand burner and a sand-bath, so that the temperature of the oil rises about 1° F. per minute. As each degree of the thermometer scale is reached the opening in the cover is exposed and a small gas flame passed over it. If no flash is observed, the opening is closed until the next trial is made. The temperature at which the flash is first observed is noted, and recorded as the flashing-point of the oil. If it is wished to confirm the result a fresh portion of the oil must be taken for a second determination, as oil that has once flashed will not again flash at its original flashing-point. The gas flame used for testing should be $\frac{3}{8}$ to $\frac{1}{2}$ inch in length, and is readily obtained by fusing the end of a piece of hard glass tube until

the orifice allows only sufficient gas to pass through at its ordinary full pressure to give that length of flame. For accurate determinations heating the cylinder in an air-, water-, or oil-bath may replace direct heating by an Argand burner. The apparatus should be protected from air-currents during the determination. It is illustrated in Fig. 11. A more elaborate apparatus for determining the flashing-point of gas-oils is the Pensky-Martens, which is extensively used on the Continent. The oil is gently agitated by small wings on a rotating vertical spindle, while the vapor in the space above the oil is more strongly agitated by a larger fan on the same spindle. The oil-container is heated through an air-bath, and its top is provided with a perforation for a thermometer, and a neat device for admitting the flash-jet as required. The test is conducted very similarly to one with the Abel apparatus. The Pensky-Martens apparatus gives very concordant results with the oils of high flashing-point, for which it has been devised. The flashing-point is usually stated in the Fahrenheit scale in this country.

FIG. 11. — Abel's Flash-test Apparatus.

"The distillation of a sample of oil gives much valuable information as to its properties. For most purposes it may be conveniently carried out in the laboratory in the manner here described. A glass spheroidal flask with a glass tubulure fused in its neck, of capacity twice the volume of the oil to be distilled, is taken, and a thermometer is inserted in the neck by means of a tightly fitting perforated cork, so that the bulb of the thermometer is on a level with the mouth of the tubulure. The latter is connected to a Liebig condenser. The neck of the flask is lightly held by a clip, and the bottom rests on wire gauze, while the sides of the flask are jacketed with the same material to protect them from air-currents. Heat is applied by means of an Argand or rose burner at first, though towards the end of the distillation a Bunsen may be needed. A convenient quantity of oil for distillation is 500 or even 250 c.c. The flask should be weighed before and after the oil is put in it, and thus the weight of the oil taken is known. The heat should be regulated so that the distillate drops from the end of the condenser at a uniform rate, and does not come from it in a stream. The temperature is read on the thermometer when the oil begins first to pass over, and afterwards as each fraction of the distillate is removed. The distillate is usually collected in fractions amounting to 10 per cent. of the volume of oil under distillation. The

specific gravity of each fraction is ascertained approximately. The distillation is pushed until increased heat drives over no more oil, and no residue, or coke only, remains in the flask. When cool the flask is again weighed, and the weight of the residue so found enables its percentage (by weight) of the oil to be calculated. The weight of each fraction of the distillate can be found by direct weighing or from the specific gravity. The total of the weights of the distillates and the weight of the residue should amount nearly to the weight of oil taken; the deficiency, which should not exceed 1 per cent., may be recorded as 'loss on distillation.' It is due to some of the more volatile distillate escaping condensation. With many oils it is desirable to use two thermometers—one for temperatures from 20° to 150° or 200° C., the other (nitrogen-filled) for higher temperatures. A thermometer which has been used at high temperatures is not accurate for low ones. The amount of water, if any, which comes over and settles beneath the oily distillate should be observed. The color of each fraction should be recorded, and a piece of moist lead paper held above the outlet of the condenser at intervals to find if sulphureted hydrogen is evolved at any stage of the distillation. The degree of blackening gives an indication of the amount of sulphur in the oil. A note should be made of all observations, and the results of the distillation should be recorded. The determination of the amount of sulphur in gas-oil is seldom made, but can be carried out by Carius' method, or by a slight modification of the fusion methods for sulphur in coal, or by burning the oil in a suitable lamp and passing the products of combustion through a washer of hydrogen peroxide or other suitable oxidizing agent, and estimating the sulphate as the barium salt.

"A good oil for gas-making should be free from water and leave less than 1 per cent. of coke on distillation. A crude oil will generally contain fractions distilling below 100° C., but the distillate now so largely employed for gas-making will be free from such light fractions. A natural oil generally contains water, though sometimes only in small quantities, and there is great divergence in the boiling-points and specific gravities of the fractions of distillate from it. Rapid blackening of lead-acetate paper should not take place until near the end of the distillation. Only the tenth fraction should be decidedly dark in color. Oils containing more residual coke than 1 per cent. may be used in certain methods of oil-gas manufacture, but are not desirable in any plant containing checker-work chambers or small outlet pipes. Provided the distillation results do not condemn an oil, it is tested for yield and quality of gas in a small oil-gas apparatus. It is not of great importance which of the numerous forms of apparatus in common

use is adopted, but the same should be used during a series of experiments, and comparisons made with tests of a standard oil in it. Paterson's, Keith's, Pintsch's, or Avery's apparatus may be used. The apparatus should be of a size to work off a gallon of oil in about three hours. The heat of the retort or tubes must be regulated according to the nature of the oil under trial; tests should be made at different temperatures to find that most favorable to the oil. The temperature should be observed with a Le Chatelier or other good pyrometer, but where this is impossible a practiced eye can judge it with fair accuracy. Not less than a gallon of oil should be gasified at each test; the gas should pass through two lime purifiers (2 feet square by 1 foot deep, two shelves) and then through a meter, the index of which should be read before and after the test to find the quantity of gas made. The temperature of the meter should be observed several times during the experiment, and the mean temperature and mean barometric pressure taken for correcting the volume of gas to normal conditions. From the meter the bulk of the gas passes to a works holder, but a small stream of it led to a 15- or 20-ft. holder for testing purposes. The pipes should be thoroughly cleared of air before this sample is collected, and the stream should be such that the holder is filling throughout the test. The sample is tested for illuminating power in the ordinary way, but it will generally be necessary to try several burners to find that most favorable to the oil. The highest candle-power found with any burner should be taken for calculating the value of the oil. Care must be taken that the gas in the small holder is thoroughly mixed; if there is any doubt about its being so, the whole of it should be burned and the photometer tests taken as the illuminating power. As a general rule American oils give the best results at a lower heat than shale oils, and the latter at a lower heat than Russian oils. The results of the tests should be worked out to give the number of candles produced by the gas from a gallon of oil burning at the rate of 1 cubic foot per hour. As the standard rate of 5 cubic feet per hour is too fast for oil-gas, the candle power at the actual rate of consumption is taken, and the nominal candle power at the standard rate arrived at by calculation. The product of the number of candles at the standard rate, and the volume of gas per gallon of oil divided by 5 (the number of feet burned per hour at the standard rate), gives a figure which represents the 'candles per gallon' obtained from an oil. This figure multiplied by 3/175 gives the pounds of sperm per gallon of oil. The pounds of sperm per gallon divided by the specific gravity of the oil, and the result divided by ten, gives the pounds of sperm per pound of oil. The results of oil tests are usually stated either in 'candles per gallon' or 'pounds of sperm per pound' of oil.

"In the United States of America crude oils are extensively used for gas-making. The specific gravity is about 0.830. As the oil flashes at or little above the ordinary temperature, it is unsuited for transport to a distance. It gives the best result at a moderately low heat. In consequence of the much larger yield of burning oil, American oils produce less intermediate oil on distillation than Russian petroleum affords.

"With the exception of petroleum, few oils are worthy of consideration for gas-making. The price of animal and vegetable oils is prohibitive; the only others available are the dead tar-oils. As tar is a product of destructive distillation at a high temperature, it is evident that it will not be greatly altered in character by exposure to a high heat. A considerable portion will merely volatilize and condense again unchanged on contact with a cool surface. The light benzene hydrocarbons will act thus, likewise naphthalene and other closed-chain hydrocarbons. The green oil from coal-tar, which remains after the extraction of phenols and naphthalene from the middle oils of the tar-distiller, contains a certain amount of gasifiable hydrocarbons and is sometimes used for gas-making. A high heat is required to produce a permanent gas from it, and the illuminating power is always low. Coal-tar 'green' oil yields about 350 candles per gallon. Oil-tar as deposited in the condensers and siphons of an oil-gas installation contains about a quarter of its volume of intermediate oil, which, when separated by distillation and freed from naphthalene, may be put through the apparatus to produce gas. The yield is, however, only about 300 candles per gallon, and the gas is of dubious permanency.

"Hirzel has proposed to take as a standard gas-oil with which results from other oils may be readily compared, one which gives a yield of 60 cubic meters of gas per 100 kilograms of oil; the gas, at a consumption of 35 liters per hour, having an illuminating power of 7.5 standard German candles. Expressed in English terms, such an oil would be one of which 1 ton would yield 21,650 cubic feet of gas, having an illuminating power of 31.86 candles. This gives 137,980 candles per ton, which is considerably lower than the value for most gas-oils in use in this country. A standard of comparison for gas-making oils, such as Hirzel has proposed, would frequently be of service."

Temperature.—The heats of the carburetter can be controlled principally in three ways: either by reducing the heat of the entire set, as by increasing the amount of steam on the generator, or adding a quarter of a turn of down-steam during an up-run, or by reducing the time of the blasting period upon the generator. More directly, the carburetter heat may be affected by reducing either the

amount of blast or blasting period, or by "blowing cold," which process consists in giving the carburetter a blast considerably in excess of that given the two other retorts. It should always be borne in mind, however, that the heat of the carburetter should be retained considerably in excess of that of the superheater; the heat may again be changed by varying the amount of oil admitted.

In the opinion of the author, it is extremely inadvisable to heat gas-oil before its admission to the carburetter. Gas-oil being a mixture of oils of various gravities, there is a tendency to break them up at too high a temperature, thereby turning the lighter hydrocarbons into lampblack, beside permitting the carburetter to "run hot"; this danger is less likely to occur with naphtha or crude oil having a regular and constant gravity. Theoretically there is some saving to the bricks of the machine by the prior heating of the oil, but this is a rule more than offset by its attendant difficulties.

Value of Oils for Gas-making.—The effort to utilize coal-tar for carburetting in water-gas manufacture has not been successful, its effect having been unsatisfactory upon the machines, as there is a tendency toward the formation of lampblack. It is maintained that the best oil for gas-making is that which contains the largest proportion of open-chain hydrocarbons (paraffins and olefins) and the smallest quantity of the ring compounds (aromatic, etc., hydrocarbons). The latter can be "cracked" or broken up into fixed compounds only at an excessively high temperature, and their illuminating power is relatively low. Generally speaking, gas-oil should be composed as nearly as possible of factors that are homogeneous (as shown by the fractions and distillates coming off within a narrow range of temperature). It will be apparent with this arrangement that at a given heat in the fixing-chambers the oil will not only become completely dissociated, but the fractions will be equally gasified; whereas, if the contrary were true, certain fractions would become gasified to the destruction or loss of others, the extremes being indicated, as before mentioned, by the production of lampblack or of residual oil or tar.

Messrs. Leather and Ross carried on an extended series of experiments (*Journal of the Society of Chemical Industry*, May 31, 1902), as a result of which they suggest that an approximate valuation of an oil for gas-making purposes can be obtained by multiplying the number of cubic centimeters of gas produced from 1 c.c. of oil by the sum of the hydrocarbon vapors plus the heavy hydrocarbons. They give tables of five oils, examined by gasifying in retorts, which may be summarized as follows.

RELATIVE GAS-MAKING VALUE OF VARIOUS OILS.

Line No.		Russian Solar.	Borneo Solar.	American Solar.	Texas Solar.	Russian Refined.
1	Cubic centimeters of gas per c.c. of oil....	465.7	301.0	442.6	397.4	429.0
	ANALYSIS OF GAS.					
2	Hydrocarbon vapors...	4.0	4.0	3.2	3.4	3.8
3	Heavy hydrocarbons ..	30.2	22.8	33.0	26.8	28.0
4	Methane.............	54.2	60.0	52.5	66.2	57.0
5	Hydrogen............	12.0	13.6	11.6	13.4	11.5
6	Lines 2+3...........	34.2	26.8	36.2	30.2	31.8
7	Lines 1×6...........	15,927.0	7,067.0	16,022.0	12,001.0	13,642.0

Of oils of different types they found that in general those containing the greatest proportion of paraffin gave the best results.

Operation Details.—It is possible in an emergency, where it is necessary to immediately cool the carburetter and superheater for the removal of checker brick, to either remove the oil-injector in the case of the carburetter, or, in the case of the superheater, to introduce through the stack-valve a $\frac{1}{2}$-in. pipe to which a hose with water supply is connected. After applying the water a short time through the center of the superheater chamber, it may be introduced into the sides through the manholes. If possible the water should *not* be allowed to reach the side and thereby loosen the linings; therefore the water should not be introduced under any degree of pressure. The carburetter in this manner should be cooled within an hour and a half; the superheater within from three to four hours. It does not pay to handle hot brick.

In checking the oil received in gas-works the instruments usually used are the Baumé coal-oil hydrometer, that has been adopted by the United States Petroleum Association, and Abel's flash-testing apparatus. In testing the gravity, corrections for temperature must, of course, be made; it is also necessary in some instances to ascertain the percentage of residue in the oil. The most rapid method is to use a wide-mouthed flask which has been previously weighed and the outlet of which is connected with a vacuum pump, in order that the oil-vapors may be rapidly removed; after distillation and cooling the flask is reweighed and the residue calculated.

It is customary with a number of water-gas engineers to allow a ratio in the carburetter of 250 No. 1 brick ($9\times4\frac{1}{2}\times2\frac{1}{2}$) for each square foot of surface in the generator. As a rule, the carburetter contains one-third and the superheater two-thirds of the brick; the total number of fire-brick used for fixing water-gas, however, depends upon a number of variables.

There is a wide difference in practice regarding the pump pressure to be maintained upon the oil-nozzle of the carburetter, the extremes employed by various engineers being from 40 to 120 lbs. It is likely, however, where the Collins injector is used, that too great a pressure will spread the oil into so wide a circle as to strike the wall of the carburetter and will run down without vaporizing; on the other hand, too low a pressure causes the oil to drop down to the center of the machine, with practically the same result, there being a rapid carbonization on account of the limited area of fire-bricks exposed: the engineer determines by experiment the results best applicable to his conditions. It has also been suggested that with high heats a high pressure and with low heats a low pressure should be used, the vaporization being more rapid or slower under these respective conditions.

The oil-storage capacity necessary in a water-gas plant depends upon these factors: first, candle power or enrichment of the gas made; second, the quantity of gas produced; third, the distance of the plant from the points supplied and the facility of communication with the same. Taking into consideration, however, strikes, accidents, and military intervention, the minimum should not be less than a thirty days' supply, from which we obtain the formula for necessary storage capacity:

$$Ga = Vt,$$

in which a equals gallons of carburetting oil required per 1000 cu. ft. of gas made (usually 5); $V=$ the number of thousands of cubic feet of gas made in 24 hours, t the least number of days' supply necessary (generally 30), and G the gallons of storage capacity (generally $6V$).

The gas pressure lost on passing through the carburetter and superheater depends, of course, upon the shape and number of the fire-brick they contain and also on the pressure upon entering the generator. When the pressure lost in passing through the generator would be six inches, the other two retorts or chambers would have a drop of from 0.5 to 1 inch each, the proportion varying with the spacing and condition of the brick.

CHAPTER III.

THE SUPERHEATER.

WHERE gas-oil is in use oily vapors of a dirty yellow color and of an exceedingly disagreeable odor are apt to escape from a machine upon the opening of the superheater stack-valve. This nuisance may be overcome by placing a pilot-light adjacent to the stack-valve, which will ignite these vapors immediately upon their escape from the orifice and permit of their consumption before entering the outside air.

Temperature.—The heats of the superheater should be maintained at a lesser temperature than that of the carburetter, for the reason that in the last-named retort the hydrocarbons or illuminants are "cracked" or broken up, and that further "cracking" or dissociation tends to deteriorate or break down their value. It will be seen, therefore, that the purpose of the superheater is for fixing or final amalgamation, and for this purpose must be materially less in temperature than its predecessor the carburetter. The heat generally used is a bright cherry in the upper portion of the machine, brightening a trifle at the lower sight-cock.

The tendency of most water-gas superheaters is to "run hot." It is possible to reduce such heat by "blowing cold," or giving to the superheater a blast considerably in excess of the other retorts. This is, however, rarely advisable, and the regulation of heat should generally be through the medium of the other machines. The heat of the superheater should hardly exceed a bright cherry at its base, with a duller color showing in its upper sight-cock, a greater heat being accompanied, as a rule, by roaring at the stack. As has been before stated, the heat of the superheater should be invariably less than that of the carburetter, the office of the superheater being to fix and permanently "set" the gas, and not to further dissociate the hydrocarbons. Perhaps the best test for the proper conditions to be maintained in the superheater is to permit a small jet of gas from the upper sight-cock during the run to impinge, through a very small nozzle, upon a sheet of white and

preferably unglazed paper. Should the heat of the superheater be too low, tar will be indicated, while a cold carburetter or excess of oil will be reflected by "uncracked" oil being carried over in suspense. On the other hand, excessive heat on the part of the superheater will be shown by deposits of lampblack, and on that of the carburetter by free carbon. The proper condition of heat and "well-cooked oil" will impinge upon white paper a seal-brown stain, varying to amber and slightly glazed. These colors will vary slightly with particular conditions and classes of oil, but, if carefully watched in connection with the results made by the apparatus and the conditions noted, form a most exact index to successful operation. The temperature of carburetted water-gas upon leaving the superheater varies from 1450° to 1600° F., this being dependent upon the heat of the retorts and the nature of the oil used.

Carbon Deposits.—It is generally possible to remove the carbon from bricks in a water-gas superheater by "burning off." This is effected as follows: The set having been let down and all dust and ashes removed, the doors are closed and a slight blast turned upon the superheater, which is then ignited by means of a little oil and a red-hot iron rod. This slight blast is then maintained until all carbon upon the bricks is entirely removed, the process usually taking some three or four days.

It is impossible, as a rule, to work this process upon the carburetter, inasmuch as the shock attendant upon the intermittent admission of oil has a tendency to fuse or disintegrate the brick, thereby "clogging" the gasway of the machine.

Carbon is not formed, as is sometimes supposed, in the take-off pipe of a water-gas superheater; it merely deposits there, and such deposit cannot be entirely prevented. It can only be reduced in quantity, its presence being detected by continual observation of the wash-box, seat drip-pot, or overflow. Here temperatures are reflected high and low by the presence respectively of lampblack and unfixed oil.

The color of crude gas leaving the superheater is affected more or less by the nature of the oil being used. Under average conditions and with the oils usually used for carburetting, opening of the superheater sight-cock admits crude gas of a golden straw tinge, without indication of oil or lampblack. Should the escaping gas show a thin bluish tinge, an absence in the proper proportion of hydrocarbons is indicated, while too heavy and dense a cloud, showing tarry or oily particles, indicates a supersaturation coming from an over-abundance of the hydrocarbons in the gas. The rich straw color and a certain dryness in the gas are under average conditions the proper mean between these two extremes. When a jet

of this gas is impinged on some white substance, such as white unglazed cardboard, it leaves a rich golden straw-colored deposit, without the presence of either tar or lampblack being in evidence.

The number of brick in the superheater is supposed to be a certain proportion to the capacity of the generator, between which retorts there should exist a certain balance; as, for example, when the generator is ready to decompose steam the superheater should be ready to fix the gas. This proportion is stated by one authority as follows: The combined checker brick in the carburetter and superheater, exclusive of the side walls, should be 28 sq. ft. per gallon of oil used per hour. A part of this serviceable area is, of course, removed from direct contact with the gas, by reason of the contact surfaces between brick and brick. Therefore the figure is better given as 20 sq. ft. of brick surface per gallon of oil per hour. These figures are based upon the use of the heavier oils, less surface being requisite in the case of the naphthas or higher distillates.

Superheater Brick.—Split bricks ("soaps"), of course, give greater heating surface for given cubical volumes than the ordinary No. 1 brick, but their use is rarely necessary inasmuch as the fixing surface in modern water-gas machines is generally excessive, and the soap or split brick are weaker and less durable or otherwise desirable than the Standard No. 1. It is the custom of many water-gas engineers to place in the superheater twice the number of No. 1 fire-brick that is allowed in the carburetter. Each set, however, as well as the conditions of operation, such as quality of oil or generator fuel used, length of blast, hour of service, etc., entails different conditions, which can be found only by systematic and careful experiment.

CHAPTER IV.

WASH-BOX AND TAR.

THE action of the wash-box or seal is largely similar to that of a check-valve, to prevent the return of the gas to the apparatus. These seals are generally made with a ratio between the wash-box and the dip-pipe areas of about 25 to 1. It will, therefore, be obvious that if the dip-pipe dips, say, 3 in. in the water of the wash-box, it will require but the rise of 3 in. of water pressure to force the gas through that seal, while before the gas can return from the box into the dip-pipe all the water in the box would have to be forced back into the dip-pipe. Taking the area ratio at 25 to 1, as before mentioned, while it takes but 3 in. pressure to force the gas into the box, it would require $3 \times 25 = 75$ in. pressure to force the gas back into the dip-pipe. (These figures are only approximate.) This same principle can be observed at a coal-gas works in the action of the hydraulic main.

Cleaning.—The following precautions are advised by the American Gaslight Association committee with regard to the cleaning of a water-gas wash-box:

"To insure safety the wash-box and connections must be thoroughly ventilated. There are two arrangements of wash-box in water-gas apparatus. In one the take-off from the wash-box is on top, and in the other it is on the side and connects directly with the scrubber. The connection from the gas outlet on top of the superheater to the wash-box varies in different forms of water-gas apparatus. In most cases there is a lid on top of what is known as the oil-heater connection, which can be opened to clean the oil-heater. Where no oil-heater is used the take-off connection from the superheater has a hand-hole cross at the top of the superheater, connecting the vertical riser from the wash-box to the outlet branch on the superheater. Where the wash-box has a take-off on top there is a valve between the wash-box and the scrubber, which can be closed and thus shuts off communication between the wash-box and scrubber. In this case, first open either the lid on top

of the oil-heater, or, in case there is no oil-heater, the hand-hole on the cross; then shut off the overflow from the wash-box to the seal-pot, open the hand-hole on top of the wash-box, and fill the wash-box with water. When the wash-box has been filled, draw off the water, open the hand-hole or manhole on side of wash-box, and remove the tar, etc. In case there is no valve between the wash-box and the scrubber, but the scrubber and wash-box are joined together by the side outlet on the wash-box, the first thing to be done is to close off the overflow-pipe from the scrubber to the seal-pot. Then open the manhole on top of the scrubber, and then the lower manhole on the side of the scrubber. Fill the wash-box with water as described above. The only difference in the two methods is that in one case you must thoroughly ventilate the scrubber in the manner described. *In any case take care that no fire comes near the wash-box or connections while the wash-box or connections are open. Do not use a light above the work.*"

Operation Details.—The wash-box should be closely watched as a check upon the heats in the carburetter and superheater. If lampblack is being produced it will show here, as will sometimes naphthalene, which, however, is more apt to appear in the multi-tubular condenser and the inlet of the purifiers; on the other hand, low heats, excess or unfixed oil will appear in the shape of free oil on the surface of the seal-pot. The safety line lies about the exact center of these extremes, as indicated by clear tar, showing with reflected light a tinge of yellow gold, its exact consistency and color being dependent somewhat upon the nature of the oil used. To repeat, however, the best test of properly fixed gas is the clarity of the tar at this point, which should be absolutely free from either lampblack or uncracked oil.

The inflow of the wash-box is generally regulated so as to admit from 7 to 11 gallons of water per 1000 cu. ft. of gas made.

The question of increased candle power through illuminants picked up in repumping of the seal-water is much debated. There is probably some recuperation from the lighter oil, but little or none from the tar, which is better extracted by a skimmer or baffle-separator introduced into the system. There are certain little advantages in the use of fresh water in the seal, as it more readily combines with CO_2 and the sulphur compounds. This is more than compensated by the high temperature usually existing in the seal-water, the water in good practice in any event never being admitted to the seal at a less temperature than 110° F.; moreover, it is likely that, in using the old water, it has already reached a point of saturation for both gas and the light hydrocarbons with which it mechanically combines, it therefore ceases to take these from the gas passing the seal-pot. The best practice

requires, therefore, that the seal-water be returned to the seal by the use of a circulating pump, having separated from it all tar, etc., which is *heavier than water*. The undecomposed steam in the gas should also be utilized here, and condensing should about compensate for any losses in water, thereby obviating the necessity for any fresh water in the seal-pot system. The pump used should be of special design for handling hot water and oil, and should have a capacity of at least 50 per cent. in excess of its maximum demand. A rapid circulation should be kept up in this water, the pump being arranged to run slowly.

Where tar separators are used the suction-pipe should be placed about 5 ft. below the surface in the last section of the separator, and the pump may then force directly into the seal-pot.

Composition of Tar.—O'Conner, in his Gas-engineers' Handbook, gives the amount of water contained in oil-gas tar upon leaving the apparatus as being 70 per cent.

The following tar analysis is taken from the work of Paddon and Goulden. The specific gravity of the tar was 0.996.

	Per Cent. by Volume.	Per Cent. by Volume Without Water.
Water	76.5	0.00
Benzine	0.28	1.19
Toluol	0.90	3.83
Light paraffins, etc.	2.0	8.51
Solvent naphtha (xylol)	4.15	17.96
Phenol	trace	trace
Middle oils (naphtha, etc.)	6.92	29.44
Creosote oil and green oil	5.70	24.26
Naphthalene	0.30	1.20 per cent. by weight
Anthracene coke	0.22 (contains 8.33 per cent. anthracene)	0.93
Coke	2.30	9.80
	99.27	97.20
Loss	0.73	2.80
Total	100.00	100.00

The following is an analysis of water-gas tar from the Mutual Gaslight Company of Savannah, Georgia:

Specific gravity at 60° F.	1.1284
Free carbon	9.84%

DISTILLATION PRODUCTS, PER CENT. BY WEIGHT.

Ammoniacal water		0.15
Oils, light—170° C.	9.18	
Middle	25.81	62.76
Anthracene	27.77	
Pitch		33.90
Loss in analysis		3.19
		100.00

Tar Paint and Pavements.—The two principal uses of oil-gas tar are, first, as a paint; and, secondly, as a paving. Its preparation as a preservative coating for pipes and metals we have described under the head of Services.

In ordinary paint for woodwork it may be boiled down to such a consistency that it will "string" between the thumb and forefinger. It should then be heated to about 150° F., and benzine added at the proportion of 1 gallon of benzine to 4 gallons of tar. No more of this preparation should be made up at one time than is required for half a day's work.

A method of utilizing oil-gas tar, which has been employed by several companies and has been of considerable profit, is as follows: An oil-boiler has been connected with the tar-well, a tar-pump being placed in series therewith. This boiler is made tight, and to the top is fixed a pipe coil acting as a worm and ending in a suitable water-condenser.

The boiler is pumped about half full of the watery tar as it reaches the well. All connections, save the end of the worm, are then closed and a fire started beneath the boiler. Evaporation takes place very rapidly, the worm first passing off aqueous vapor, then anthracene, and finally a fair quality of creosote. The residual left in the boiler or body of the retort is a fair quality of what may be termed oil-pitch, a commodity having much greater value as a preservative, painting, or roofing material than has the ordinary oil-tar.

The following formula for making tar pavements or sidewalks is given by a committee of the American Gaslight Association:

"For pavement or sidewalks applied as a finishing surface 2 to 3 in. thick upon a foundation of broken stone or coarse clinker, the top dressing of finer ashes or coke breeze, boil the tar until at 60° F. it has the consistency of vaseline. In the absence of special furnaces for the work place a sheet of boiler-plate upon stones in

the vicinity of the paving to be laid, so that it will be about one foot above the ground. On this plate throw building sand and underneath kindle a fire of wood or coke. Turn the sand over with a shovel until well heated. Gradually pour on the thick tar, meanwhile turning and mixing the mass until the sand is uniformly black and of such a consistency that a ball of it will just hold together while hot. While hot and carrying the mixture in heated iron barrows or on shovels, apply where required, leveling with a hot rake and ram with a hot rammer. Then sprinkle the surface with fine sand and roll, using preferably a heavy hand roller. This may be made of a piece of cast-iron street main, with ends plugged and center filled with sand."

Tar-pumps.—In connection with the handling of tar and concerning the proper pumps for the transportation of same, the committee also has to say as follows:

"The principal points of valve design to be observed are that the valves should afford full, free openings, and that the seats should be so arranged that no lumps of heavy tar or of solid matter in the tar will lodge on them and prevent the valves from closing tightly. A hinged valve is better than the ordinary form of pump-valve, since in the latter form the center guide obstructs the opening to a great extent, while the hinged valve affords a free and unobstructed opening. These valves are sometimes used with horizontal seats and sometimes with seats inclined at an angle of 45°. With the inclined seat there is less danger of any solid matter remaining on the seat and keeping the valve open.

"One company that handles a great deal of tar employs pumps in which the valves are hinged and the seats horizontal, and says that they have found them to give complete satisfaction. In this case the valves are not provided with springs, being prevented from opening too far by stops and being closed by their own weight as soon as the pressure is removed from beneath them. In other pumps springs are used with the same kind of valves to keep them from opening too far and to assist in closing them promptly when the plunger changes the direction of its travel. These springs should be made of iron or steel."

In handling tar a slow-running pump, preferably of the rotary type, should be used, with non-restricted orifices, all parts easy of access for repairs or cleaning. The internal resistance of the pump, by which is meant the resistance offered to the passage of the tar, should be a minimum. If, however, the reciprocating type of pump should be used, it should be entirely of iron or steel with ball- or trap-valves and with extra large inlet and outlet. The long stroke-pump will be found preferable, and the size selected should be at least double that of an equal capacity for water.

Separation.—There are two occasions when tar should be condensed or separated from its accompanying medium; the first, that of tarry vapors in the gas, which continue as far as the purifiers and greatly injure the purifying material by covering it with a thin, oily insulation, and which may be remedied by placing in the inlet of each box a layer of planer chips, or, better still, by devoting the first box in the series entirely to chips and shavings, these to be changed immediately upon becoming foul. The other occasion is the separation of the tar from the water with which it leaves the condensers, scrubbers, or seal-pot. This separation is extremely advisable, both for the preservation of the tar and the rendering of the water fit for renewed use, and also because, in case the water, either as a whole or in part, is not used again or finally finds its way to the works drains or sewers, it should be free from all tar and heavier oils, which are of incalculable detriment to it. It is the custom of many cities to prohibit the running of tar into their sewerage systems, and inasmuch as it discolors any neighboring watercourse its disposal through drainage invariably becomes a considerable incubus.

For the separation of the tar from the water, however, under conditions such as we have just recited, a form of separator or

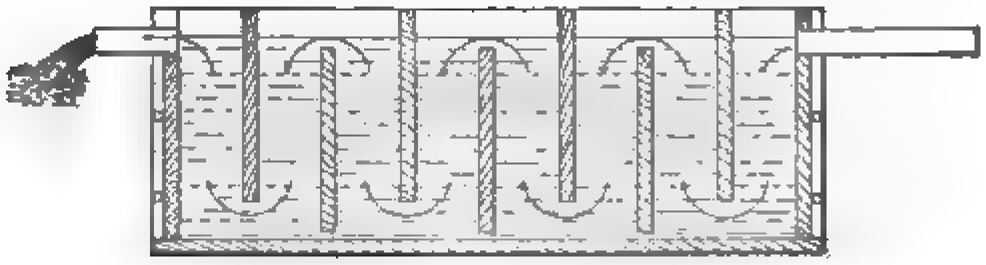


FIG. 12.—Tar-separator.

skimmer is illustrated in Fig. 12. This is little else than a long, oblong trough, in which the greater the width the better, the velocity of flow being thereby decreased. In this trough are placed lateral partitions or skimmers marked *a*. The intervals between them are about 18 inches. Alternate partitions reach from a foot above the water-line to within a foot of the bottom of the box, while intermediate partitions reach from about 4 inches from the bottom of the box, or through to a point, say, 4 inches beneath the waterline. The sides of the trough should be equipped with proper bungs for drawing off the tar, and to insure perfect separation the outlet of the trough should be so arranged that a strainer of bagging or fine wire netting can be applied, cotton bagging being a very good material. In addition to the above separator it is well to have upon the outlet a trough which may be filled loosely with pieces of coke, which will be found an excellent strainer, as the

rough side of the coke adheres to the passing tar which attaches to it and serves to give the water its final purification. The coke should be maintained in a cleanly condition, the fouled coke being burned.

A limited amount of water-gas or oil-tar can be used to some advantage on the generator of a water-gas set, and will be found to have an enriching quality of between 5 and 6 candles per gallon. Not more than one-half gallon of tar, however, should be admitted to 1000 cu. ft. of gas manufactured. The tar should be pumped into the top of the generator preferably with an oil-spray, similar to that used on the carburetter.

The West Chester (Pa.) Gas Co. is using a cream-separator, such as are used by dairies, for the separation of water-gas tar from its entrained water. A similar separator for this purpose is made by Messrs. Geo. Shepherd Page Sons in England.

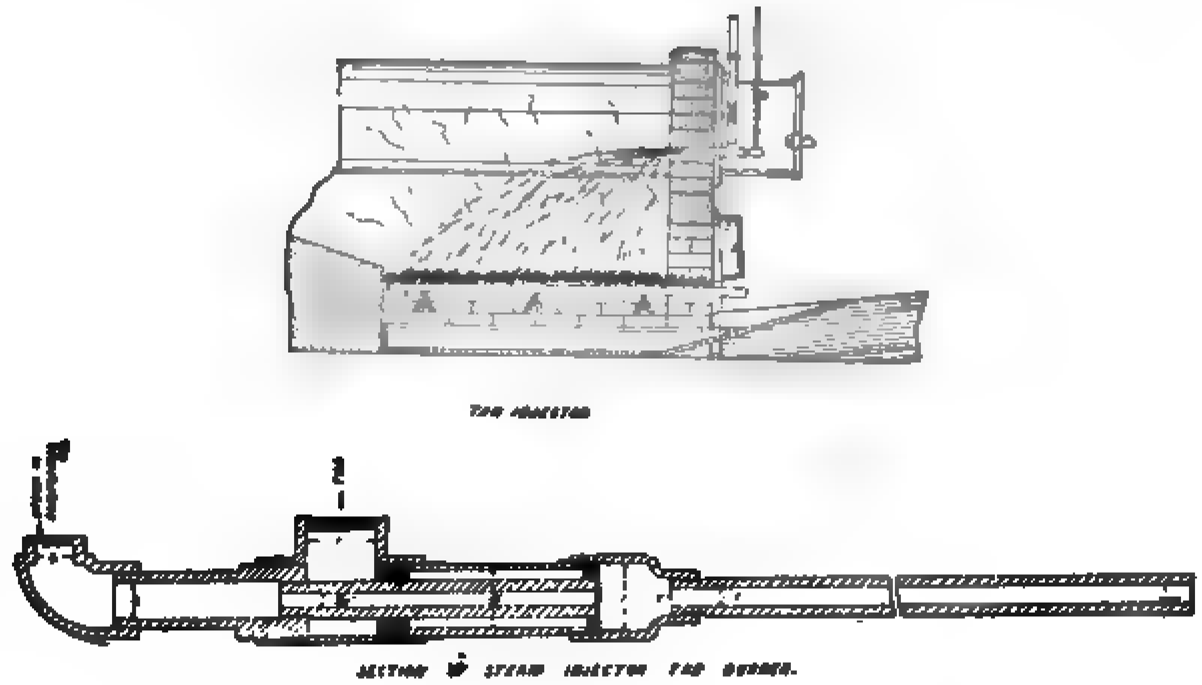


Fig. 13.—Steam-spray Tar Burner.

Burning Tar.—The chief disadvantage in using tar in combination with oil as an enricher appears to be the clogging of the checker brick in the carburetter and superheater, so the more general practice appears to be burning the tar under the boilers, which is generally accomplished by the ordinary steam-jet spray before described. An excellent method for preparing tar for this usage is by the use of two tanks, in the larger of which a large steam-coil is inserted, by which the water is evaporated, thus leaving a pure oil-tar residual. This tar is then drawn off into the second tank, from whence it is fed directly to the burner. The levels of these

tanks should be arranged, if possible, so that this last operation may be performed by gravity. It is stated that 2.6 gallons of oil-tar are equal to a bushel of coke as fuel under steam-boilers. A form of burner is shown in the illustration (Fig. 13).

Newbigging's Handbook gives 6 gallons coal-tar as being the equivalent of three bushels of coal when properly fired under a boiler.

CHAPTER V.

SCRUBBERS.

As a matter of fact the seal-pot or wash-box is the first in the series of purifying apparatus in a water-gas setting, but the passage of the gas is relatively so rapid at this point as to make its action extremely imperfect, and the first heavy duty in cleansing and purification devolves upon the scrubber, which succeeds the wash-box in series and precedes the condenser.

Operation Details.—Great care should be taken with the regulation of water in this apparatus, as a surplus tends to wash out and carry off mechanically the heavier hydrocarbons.

This water should usually be the overflow from a multitubular condenser, unless this should run too high in temperature. A fresh-water connection should always be available for such occasions, when a sufficient amount of cold water may be admitted to lower the gas to the degree required, namely, about 170° to 190°, at the outlet.

The material used to fill scrubbers is generally that presenting the greatest possible surface to the action of the gas and water. King's Treatise recommends the use of small stones, pebbles, coke, brickbats, tiles, or timber. Of these materials coke is perhaps the best by reason of its lightness, although it has a tendency to crumble should the height of the column be sufficient to produce a crushing weight.

Trays.—Sir George Livesey is responsible for the method of using trays of thin boards ¼ in. thick, 3 in. high, and spaced 3¼ in. apart, having an area proportioned to the diameter of the scrubber. The most common practice is to use boards ⅜ inch to ½ in. thick, 4 inches to 10 in. high, and made up with about ½-inch spaces between. These trays are placed horizontally within the scrubber, tier by tier, in a manner known as "thatched," or one tier placed so that its length is at right angles to that of its predecessor. Props or supports are usually placed at certain intervals to allow the gas to redistribute and to facilitate the removal

of a portion of the tray without removing the entire contents. The relative merits of such trays as described and those of coke are about as follows:

For the coke, lightness, cheapness (the coke may be burned after it becomes saturated), and the convenience of the installation.

That claimed for the boards or trays, freedom from stoppage, ability to be cleansed and used again, greater contact service for

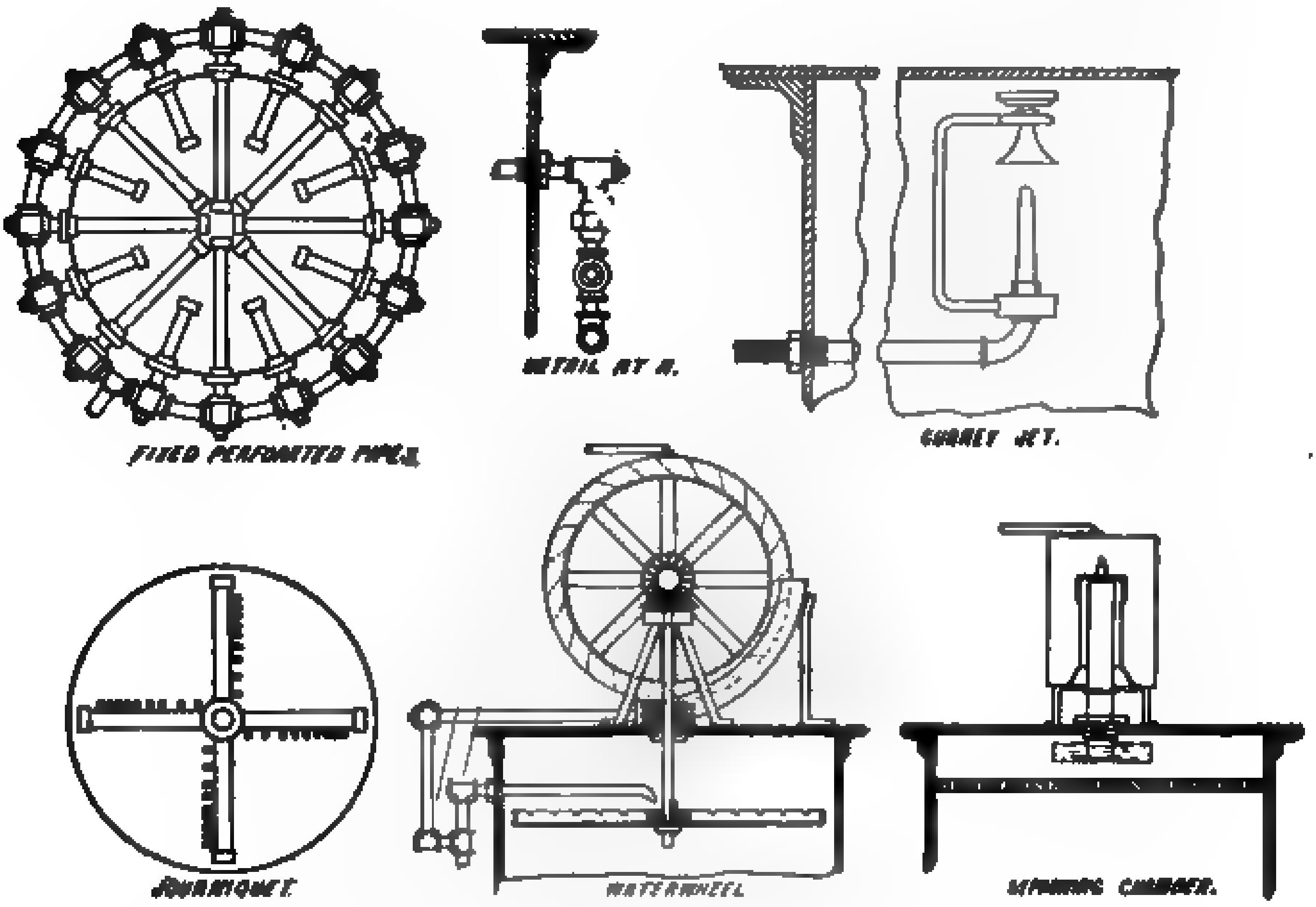


FIG. 14.—Water Distributors for Tower Scrubbers.

both gas and water, slower speed of travel of gas, greater efficiency for space occupied.

Sir George Livesey gives the following comparison of material for each cubic foot of space occupied:

Contact surface of coke, 8½ sq. ft. per cu. ft.
Contact surface of boards, 31 sq. ft. per cu. ft.
Coke occupies ½ cubical contents.
Boards, ¼″, spaced 1″ centers, occupies ¼ cubical contents.

Sprays.—The greatest difficulty to be overcome in wet scrubbers is to obtain an even distribution of the water-spray over the

material. There are for this purpose a number of devices, some of which are movable, as the tourniquet pattern (see Fig. 14). But perhaps the more practicable are such devices as the Gurney jet and the radial spray, as illustrated. These last-named should be carefully regulated as nearly as possible to throw an equal amount of water evenly distributed over the entire area of the scrubber.

Water Analysis.—In water analysis for all practical purposes, it is customary to divide the operation into two parts:

1. Total Incrusting Solids: Oxide of Iron, Calcium Carbonate, Calcium Sulphate, Magnesium Carbonate, and Magnesium Sulphate.

2. Non-Crusting Solids: Magnesium Chloride, Alkaline Carbonates, Alkaline Sulphates, and Alkaline Chlorides.

In a rough-and-ready analysis it is usually enough to begin with, say, muddy water, settled; decant, weigh sediment; filter, weigh suspended matter. Take 250 c.c. filtered water and titrate with decinormal HCl, using methyl orange as indicator. This gives total alkalinity of carbonates. To the same sample add excess NH_3, precipitating Al_2O_3, Fe_2O_3, and most of the SiO_2; filter, ignite, and weigh oxides.

Precipitate calcium in this sample with ammonium oxalate; filter, ignite, and weigh as calcium oxide.

To the filtrate add sodium phosphate and more ammonia; filter, ignite, and weigh; calculate as magnesia.

To this filtrate add HCl and $BaCl_2$; weigh as barium sulphate and from it calculate the sulphuric acid.

On a second 250 c.c. sample, determine chlorine by titrating with standardized silver nitrate, using potassium chromate as indicator.

The probable combinations may be worked out thus: Calculate all magnesium as carbonate (if excess of magnesium remains, calculate as sulphate); combine excess of CO_2 with calcium (if further excess of CO_2 remains, combine with sodium); calculate remaining calcium as sulphate, remaining sulphuric acid with sodium, and chlorine with sodium. This is applicable to boiler waters and gives reasonable accuracy.

CHAPTER VI.

CONDENSERS.

THERE is, perhaps, no item in the manufacture and distribution of gas more important than its proper condensation. This should lie between two limits. The first, and probably more important to avoid, the sudden cooling of the gas, contracts the vapor and causes a precipitation of the benzol vapors and heavier hydrocarbons; the second requires that all condensation should, if possible, be removed from the gas before leaving the works, as otherwise stoppages in the mains, produced either from the low heat in the machine, causing tar, or the high heat, forming naphthalene and lampblack, will invariably ruin the meters, causing the diaphragm to become hard and stiff, closing services, reducing pressure, forming traps, and especially affecting Welsbach or incandescent burners.

Temperature.—In order to obtain proper condensation a careful study of the prevailing conditions must be made in each case and test of the temperature of the gas made at various junctures in its passage through the works. The writer suggests the following approximate temperatures which should follow as the result of gradual condensation:

Outlet of	Deg. F.
Wash-box	220
Scrubber	170–190
First condensers	120
Relief-holder	70

The last depends somewhat upon the temperature of the atmosphere.

It is manifest that in order to prevent shock or sudden chill to the gas the coolest gas and the coolest water should be brought into contact; for example, cold water only should be turned

into the last condenser, the overflow from which goes back into the scrubbers and in turn into the seal-pot, thereby causing the current of water to flow in opposite direction to the current of gas, the water gradually warming and the gas gradually cooling so that the water at the seal is almost of an identical heat with the gas, being warmed throughout its passage; while at the relief-holder the gas is of a temperature identical with that of the water, being cooled throughout its travel.

Jas. S. McIlhenny, engineer and superintendent of the Washington (D. C.) Gaslight Co., has designed a system of condensing

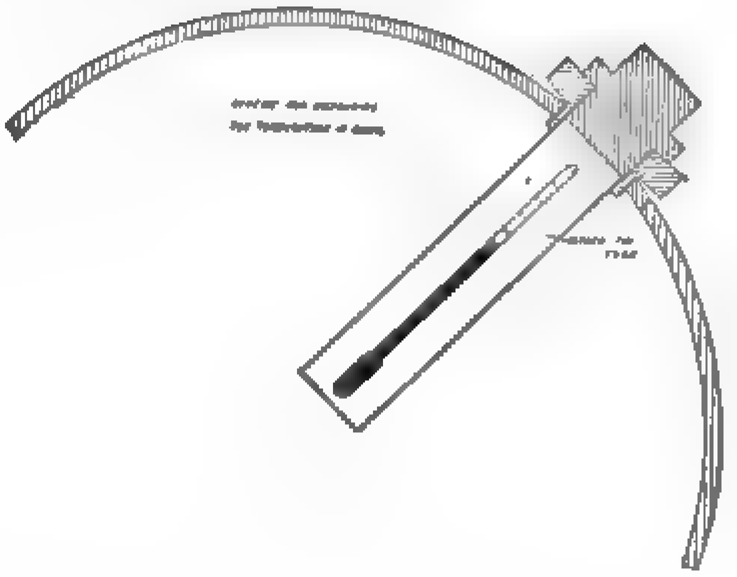


FIG. 15.—Method of Ascertaining Temperature of Gases.

apparatus which very nicely proportions and graduates this cooling process, and which, through an easily controlled mechanism, accurately and mathematically apportions the exact amount of cooling surface necessary to the gradual cooling of any given amount of gas. This apparatus is capable of accommodating itself to a very large or small quantity of gas output.

Surface.—As to the amount of condensing surface necessary to properly cool a given amount of gas, authorities differ very widely. Butterfield, one of the best English authorities, gives 150 to 200 sq. ft. condensing surface per 1000 cu. ft. of gas passed per hour. Newbigging gives 10 sq. ft. per cu. ft. per minute. Perhaps one of the best is Raissner's rule of 3.65 sq. ft. of cooling surface per 1000 cu. ft. per 24 hours as a minimum and 4.56 sq. ft. per 1000 cu. ft. as the best practice. The above calculations were made for atmospheric condensers.

In multitubular water-condensers, where the difference in temperature between the gas and the cooling medium can be regulated by the amount of water admitted, the amount of sur-

face depends naturally upon the reduction in temperature required. Suppose it were necessary to lower the temperature of the gas 63° (that being the extreme difference in temperature between the gas and the water at the gas-inlet of the condenser) to an average difference of 36.5° F., it would then be necessary to have 1.71 sq. ft. of water-cooled surface and 1.19 sq. ft. of air-cooled surface per 1000 cu. ft. of gas per day.

If the water is passed through the tubes and the gas outside the tubes in the condenser, then the shell usually affords about 1 sq. ft. of air-cooled surface in addition to the water surface. When the gas is passed through the tubes there is no air-cooled surface except the small amount around the gas spaces at the top and bottom. These condensers will show average differences in temperature between the gas and the water of over 10° F., and their great difficulty, as is almost invariably true with all water-cooled systems of condensation, is that the chilling of the gas is too sudden and a precipitation of the illuminants thereby results.

The writer is of the opinion that the burden of testimony is to show that at least 8 or even 10 sq. ft. of water-cooled surface should be installed for each 1000 cu. ft. of rated maximum capacity per day of the condenser, and that, such apparatus being at the command of the works engineer, he should then closely watch the temperature of his gas throughout its course, and, by the proper admission of water into the water-inlet of his last condenser, maintain a gradual and equal cooling throughout the entire process.

A. G. Glasgow in 1892 made the statement that it required 90 gallons of water per 1000 feet of water-gas manufactured for condensing, cooling, and scrubbing. Of course the amount of water required for condensing gas to any given temperature will depend largely upon the area of the condenser and atmospheric conditions.

Essential Principles.—Next in order to the recuperation of heat lost from water-gas sets as an economic condition, the subject of condensation is most important; it is but little understood, and, moreover, is so dependent upon local conditions, environment, climate, etc., as to make impossible any arbitrary procedure in the matter. It is conclusively proved that deposits of naphthalene, freezing of services, and the various troublesome stoppages are positively prevented by the thorough drying of the gas, and it is doubtful if any engineer properly realizes the improvement in service rendered, especially along the line of incandescent lighting, the maintenance of meters, etc., that would ensue upon the establishment of a perfect system of condensation. Broadly speaking, in the opinion of the writer, this would be along the following lines:

The passage of the gas should be slower at the commencement of its condensing course, and its impinging during the mechanical portion of its passage should be less violent than later on, where the gas has attained a somewhat lower temperature. To effect this the velocity of the gas should be slowest at the beginning of its passage, gradually increasing in speed throughout its course. As it gradually decreases in temperature there is a shrinkage in volume and a corresponding precipitation of both aqueous vapors and hydrocarbons. The loss of the latter is considerably less where the temperature is reduced very gradually and the direction of the flow of gas and water arranged in reverse directions.

It must be remembered that the affinity of gas for water at any temperature is very great, and that it will take up and recombine with substances at any stage of manufacture or distribution, the principal points of contact being the hydraulic main, seal-pot, scrubbers, purifying-boxes, station meter, and the water-seals of the holder, the last named being much more important than is commonly realized.

The writer therefore suggests greater condenser capacity with a slower rate of flow, and a condenser, dry scrubber, or shavings purifier containing some absorbent to be placed at the outlet of the storage-holder or immediately adjacent to the distribution outlet. This would allow but one remaining chance for the reabsorption of condensed materials, such as are found in the drips along the mains. These drip-pots should be maintained as clear and free from deposits as possible, a matter which would not prove difficult where the gas handled is dry and originally free from moisture.

As has been before said, the theory of condensation requires that, with each degree of decrease in temperature on the part of the gas, a portion of aqueous vapor or water be deposited; and that this shall be done gradually and without excessive friction upon the gas, so that the hydrocarbons will not be disturbed, is the fine art of proper condensation. As will be seen, this depositing of water on the descending scale of the thermometer is theoretically directly the reverse of fractional distillation. Unfortunately this does not work out completely in practice, for two reasons, viz.: first, that in this precipitation the entrained hydrocarbons are mechanically separated; and, second, the aforesaid affinity of gas for water under any condition tends to its recombination at any period of its travels; also the volume of the gas may be due to pressure as well as temperature. The point of complete saturation of gas for hydrocarbon vapors is extremely uncertain, the behavior of the gas being different under varying conditions, environment, and pressure. It would seem that a system of dry condensation

would be extremely advantageous, which would afford the gas no opportunity to recombine with moisture, for this recombination and subsequent precipitation constitutes a washing process which eventually removes from the gas a considerable proportion of its hydrocarbons.

The difficulty has been that any dry desiccating material, during its first stage of use or when first renewed, would act too harshly upon the gas, mechanically stripping it of many of its valuable contents; while later on, when permeated with these ingredients, it would reach the point of saturation and cease to act at all. A material, if found, which would maintain for any length of time the mean between these points, would prove a valuable aid to purification.

There is no doubt, however, that the gas when leaving the works should be perfectly fixed and dry, and to this end the writer again urges the efficiency of a proper condenser at the outlet of the storage-holder. The improvement in service gained through the supply to the consumer of a perfectly dry gas is most marked not only by the avoidance of naphthalene and various deposits, and the damage done to the diaphragms of meters, incandescent mantles, ranges, etc., but the removal of moisture promotes a very considerable increase of candle power, in addition to which the flat-flame light is whitened and materially improved in color and luminosity.

This feature has been proved by experiments in high-pressure transmission, results showing that about 65 per cent. of moisture can be taken out of the gas by 10 lbs. per sq. in. compression, while at 20 lbs. pressure practically all moisture disappears. Proportionately, however, the greatest amount of moisture is removed up to and by a compression to 6 lbs. per sq. in.

CHAPTER VII.

PURIFIERS.

Testing for Impurities.—The following are the simplest qualitative tests for ascertaining the presence of impurities in gas:

For carbonic acid allow the gas to bubble through lime-water; if present the water will become thick and cloudy.

For H_2S impinge the gas through a pet-cock on a piece of paper which has been wet with acetate of lead (sugar of lead) in solution; its presence (H_2S) will be indicated by the discoloration of the paper, a shade of brown appearing, the amount of the discoloration depending upon the quantity of sulphureted hydrogen contained in the gas and the length of time given to the exposure.

A similar test to that for H_2S is made for the presence of ammonia, only turmeric paper is used instead of acetate of lead.

The test for tar is usually made by permitting a stream of gas to impinge upon a piece of white (and, better, unglazed) paper. If the paper receives a dark, dirty, or tarry stain, the presence of tar in the gas is indicated. A continuous test for tar may be made by passing a stream of gas through a test-tube loosely filled with cotton-wool, in which case should tar be present the wool will become discolored.

The places at which these tests should occur are usually such situations as would indicate the complete or imperfect gas purification, as, for example, the test for ammonia would be the outlet of the last scrubber or washer; that for CO_2 and H_2S generally at the last purifying-box in the series; and that for tar at the outlet of the tar-extractor, condenser, or even the sight-cock in the superheater. It is sometimes necessary, however, to make tests for tar and other condensations (for which purpose the cotton-wool test is preferable) in the center of the distribution system, or at the fixtures of some consumer; this is necessary when tar, naphthalene, or other mechanical impurity is causing trouble to gas arcs or other incandescent-lighting burners.

Purifying-houses are not an absolute necessity, as it is possible

to maintain the boxes at a proper temperature by means of a steam-coil, although it is the experience of the writer that even in the colder climates the chemical action occurring in the box generates sufficient heat to deliver the gas at the outlet at an equal temperature, if not greater, than that at which it enters the box. For exposed work, however, he strongly recommends boxes of the Doherty-Butterworth type. The maintenance of such boxes is practically reduced to the annual painting, and the danger of explosion, due to the formation of explosive mixtures in purifying-houses, is entirely obviated.

Leaks.—In leaks in holders and purifying-boxes occurring between the lap of the plates where such plates are too thin to calk and inclined to buckle and separate, a temporary stoppage can be made by rolling tin-foil into small rolls and calking in between the plates with a sharp tool, after which the whole should be heavily shellacked.

Precautions.—Explosions have often occurred in purifying-houses through the breaking of incandescent-light bulbs. This should be guarded against. Lamps have been successfully used with a double screen, increasing the size of the wire one-half.

Preservation.—A film of heavy petroleum or lubricating-oil carried upon the seals of purifying-boxes tends to prevent the rusting of their sheets.

Sulphur Removal.—The chief reason for eliminating sulphur and sulphurous compounds from gas is the fact that they burn to sulphurous oxide, a compound disagreeable to breathe and on some occasions forming exceedingly small quantities of H_2SO_4. The amount of sulphur in gas, however, as ordinarily purified, is too small to be appreciable.

The two methods of purification most commonly in use may be stated as

1. Purification where the material is handled for revivifying, and

2. Revivifying *in situ*.

It is not the desire of the writer to discuss the various advantages of these two methods; they depend for their adoption largely upon the relative cost of labor and installation.

In the *in situ* method probably the best plan is to connect a small air-pump, such as that made by the Connelly Iron Sponge & Governor Company, in such manner that somewhere in the neighborhood of 1 per cent. of air is admitted into the purifiers with the gas and thus revivifies the oxide from the effects of the sulphureted hydrogen. Even with this method, however, the oxide must be periodically changed, as it becomes foul with tar and oil; also the moisture in the gas eventually causes the

oxide to crystallize and become hardened, thereby materially increasing the back pressure.

Purifying Material.—Where it is desirable merely to remove from the gas sulphureted hydrogen, oxide of iron can be manufactured cheaply and of good quality as follows: A large quantity of clean gray iron borings, free from steel, brass, and other metals, should be put in a trough similar to those used for mixing concrete. To every 500 lbs. of these borings 20 lbs., say, of crystal rock salt may be added and the whole wet down by throwing on buckets of water after the manner of slaking lime. The mixture should then be turned with a fork and again wet daily, all lumps and hard particles being broken up, sifted, or thrown aside, until oxidation is complete. It may then be mixed with clean shavings containing no pine rosin or other gum, at the ratio of 56 lbs. of the oxide of iron to a bushel of the mixture.

In those instances where it is regarded advantageous to remove carbon dioxide from the gas (in regard to which see table on Effect of CO_2 on Candle Power), lime must be used and should be slaked after the following manner: A layer of the best lime, say 5 in. thick and unslaked, should be evenly spread on the floor of the trough as described above. It should then be wet by throwing on buckets of water. At no time should a hose be used, as the largest possible quantity of water should come in contact with the greatest surface of lime simultaneously. Small jets of water tend to slake the lime unequally and to make it hard and full of lumps, besides causing a large portion to be burned out and inert.

The iron borings used for reduction to oxide of iron may be tested by passing through a screen with a mesh not greater than $\frac{1}{8}$ in. Borings, obtainable from the average machine-shop, are coated with lard-oil, or other grease used for the lubrication of the cutting-tool. This oily coating serves as an insulation against oxidation, but can be in a degree overcome by the mixture with the borings of unslaked lime before their wetting with water or brine.

Capacities of Purifiers.—In purification the slowest possible velocity should be obtained in order to permit time for chemical combination. It should not materially exceed $\frac{1}{4}$ in. per second, considering the box empty. The purifying material generally occupies about three-fourths of the contents of the box, leaving one-fourth for voids. The gas will therefore actually pass through these voids at a velocity of about $\frac{3}{4}$ in. per second.

One of the largest gas-engineering concerns in America constructs its boxes for ordinary conditions upon the following calculations: Taking a velocity of $\frac{1}{4}$ in. per second for the area of

a purifying-box (which is equivalent to a velocity of 1440 ft. per 24 hours), each square foot of purifying area can purify 1440 cu. ft. per 24 hours. The following table of capacities has been figured from the above and will be found satisfactory for ordinary conditions:

Size of Boxes. Feet.	Approximate Capacity per 24 Hours. Cubic Feet.
6× 8	70,000
8× 8	92,000
8×10	115,000
8×12	138,000
10×10	144,000
10×12	173,000
12×12	207,000
12×16	276,000
16×16	369,000
16×20	461,000
20×20	576,000
20×24	691,000
24×24	828,000
24×30	1,037,000
30×30	1,296,000
30×36	1,555,000

The above capacities are for ordinary conditions and for proper depth of purifying material when oxide is used, the active oxide being between four and five feet in depth.

It will be noted that almost all the empiric formulæ given for ridding crude gas of H_2S are based upon coal-gas purification, and inasmuch as coal-gas contains from 400 to 800 grains of sulphur compounds and carbureted water-gas contains only about 10 to 15 grains of the same per 100 cubic feet, a smaller area for purification will serve in the case of water-gas than that designated by old authorities.

Clegg's rule for the area of purifiers was 1 ft. area for every 3600 cu. ft. made per day.

Newbigging's rule for the area of purifiers is: The maximum daily make multiplied by 6 and divided by 1000 equals the number of square feet area in each purifer.

Anderson's rule for lime purifiers was that the rate of flow of gas through the purifier should not exceed 2000 cu. ft. per foot of surface per 24 hours.

As to construction, the thickness of cast-iron purifier plates should never be less than $\frac{5}{8}$ of an inch, and they should be the

best quality of casting. The usual width is 5 ft. Flanges for bottom plates should be 2¾ in. by ¾ in. over and above the thickness of the plate. Strong brackets should be fixed under each lute, as the strain is greatest at this point. Larger plates than 5 ft. square are liable to warp in casting.

The depth of water-seal in purifiers varies from 12 in. to 30 in., the width from 4½ in. to 8 in. As a matter of fact the seal should never be less than 18 in.

A formula for calculating the size of connections on purifiers is as follows: Diameter of connections in inches equals the square root of the area of purifiers.

The economical depth of oxide seems to be between 4 and 5 ft., regardless of the area of the box.

As a matter of fact the installation of purifiers beyond a certain extent is largely a matter of first cost. Where it is practicable to make the expenditure, the four-box system, having a center valve by which any combination of three can be made, is most advantageous. The purification of gas is a dual process, being partly mechanical and partly chemical. For example, the sulphur is removed by chemical union with the oxide, while tar, oil, and condensation are removed by impinging upon the purifying material. It is, therefore, a marked advantage to have an ample equipment affording sufficient area for purification and at the same time enabling a reserve, so that while one box is thrown out, the balance of the equipment is ample to carry on the work. This throwing out or cleaning should be done in rotation, making connections permitting of any possible combination between the boxes.

In passing gas already purified through foul oxide it is possible to pick up impurities in transit, such as CS_2. It is, therefore, manifest that the passage of the gas should be so conducted as to pass the foul gas first through the dirtiest box, or that least recently cleaned. It should then pass through the boxes in such order as to leave the cleanest box last, it being arranged, if possible, that the last box in the series be kept as absolutely clean as practicable, thereby removing from the gas any impurities which may remain in it due to a surcharge or a lack of combining strength of the oxide in the preceding boxes, which may, possibly, have passed the point of chemical saturation.

In many works it is customary of late years to build concrete purifiers, these having the advantage of cheapness and extreme durability. It is also possible to build these out of doors, thereby effecting a saving of floor-space inside the works, lessening the original cost of buildings, etc. These boxes are not as convenient for the handling of purifying materials as the elevated box. High boxes

greatly facilitate the labor in removing and replacing the oxide during revivifying where the *in situ* method is not adopted, as they are built with dumping-trays and cleaning-valves which enable the workmen to readily drop the entire contents upon the floor below. This floor, by the way, should be either of concrete, cement, or brick, by reason of the great heat attained by the sulphur in the oxide during its recombination with oxygen. In fact, all portions of the purifying-house should be well ventilated and as nearly as possible fire-proof. Nine-tenths of the explosions occurring in gas-works happen in this department, the danger being greatly diminished where there is free ventilation, and where any gas escaping through blowing-boxes, evaporation of water from the lutes, leaks, etc., does not have an opportunity to collect in sufficient quantities to form an explosive mixture. Only electric incandescent lights should be permitted in purifying-houses. Where they can be used, reversing valves or center valves are unquestionably of great advantage over the old and complicated multiple-valve system, and will be found a great economizer of space and time.

Making Oxide.—The following synopsis of purification is taken from one of the publications of the Gas Machinery Co.: The sesquihydroxide of iron, $Fe_2(OH)_6$, is the most active form of "oxide," but is very unstable, decomposing when heated to about 100° and forming $Fe_2O_3.3H_2O$. This last compound forms the most active constituent of "oxide," combining with the sulphureted hydrogen in two ways:

$$Fe_2O_3.3H_2O+3H_2S=Fe_2S_3+6H_2O \text{ or}$$

$$Fe_2O_3.3H_2O+3H_2S=2FeS+S_2+6H_2O.$$

The bulk of the sulphureted hydrogen is absorbed according to the first equation, probably about one-fifth according to the second equation.

Various methods are used to make oxide, the principal object being in every case to obtain the ferric oxide in as fine a state as possible and intimately mixed with soft-wood chips, shavings, or sawdust. Pine or spruce shavings are best, as they contain no objectionable tannic acid found in oak, poplar, or whitewood. An oxide should always be alkaline.

Method 1.—Mix clean fine cast-iron borings with sal-ammoniac in proportion of 20 lbs. to 1 oz., distribute on floor in layer of about 6 inches, and allow it to rest for at least three weeks, turning and wetting the borings every few days. Mix with soft-wood shavings or chips, previously wetted to make material weigh about 40 lbs. per cubic foot.

Method 2.—Mix coarse sawdust or small chips with slaked lime in proportion of four barrels of sawdust to one of lime. Pour copperas dissolved by steam over same, using about 9 pounds of copperas per bushel of shavings. Dissolve 1 lb. sal-ammoniac in water and mix with 20 lbs. of iron borings. Then mix sawdust and lime with borings.

Method 3.—Spread pine shavings in a layer of about 18 inches; cover with 3 inches of previously rusted cast-iron borings, sprinkle with salt water and mix thoroughly, turning over every day for about one week.

It is good practice in the manufacture of purifying material to mix the sawdust or shavings with the iron borings prior to oxidization, so that the iron in rusting forms a coating or crust upon the shavings, and is better retained in the material.

Where ground cork can be obtained at a reasonable price it can be used as the base of purifying material with great advantage over shavings, for the following reasons: It does not become soggy, cake, pulverize or, owing to its spongy nature, become compressed as do other materials, thereby greatly relieving the back pressure thrown by the box; its back pressure is only one-third that of the material ordinarily used. As 50 per cent. more oxide can be mixed with ground cork than with either sawdust or shavings, the capacity of the box is increased 50 per cent. Cork can be obtained as the waste from cork factories, and although the initial cost is invariably greater than sawdust or shavings, it is sometimes offset by its other qualities.

Ground corn-cobs are also in use as a substitute for cork, and it is claimed for them that they possess nearly if not all of the qualifications possessed by cork. Their cheapness is a great recommendation in their favor. The following table gives the weights of one bushel (2150 cubic inches) of different purifying materials:

Material.	Lbs. per Bushel.
Pine shavings	5.25
Ground cork	6.
Pine sawdust	12.75
Ground corn-cobs	15.
Iron oxide	112.

There is authority for the statement that 1.5 per cent. of air admitted to the purifying-boxes with the gas will add 25 per cent. to the purifying capacity.

Preparing Lime.—Baker's Masonry Construction gives the following characteristics for good mortar. Lime: 1. Freedom from cinders and clinkers, with not more than 10 per cent. of other im-

purities, as silica, alumina, etc. 2. Chiefly in hard lumps with but little dust. 3. Slakes readily in water, forming a very fine, smooth paste without any residue. 4. Dissolves in soft water when this is added in sufficient quantities. These simple tests can be readily applied to any sample of lime.

Common lime is a substance resulting from the calcination of pure, or nearly pure, limestones, such as marble or chalk at a high temperature, applied for a certain time to drive off the CO_2 in the limestone. It principally has calcic oxide with 3 to 10 per cent. of impurities, silica and alumina, magnesia, oxide of manganese, and trace of alkalies. It is highly caustic, with a strong affinity for water, rapidly absorbing about one-fourth of its own weight, which absorption increases its temperature to an intense heat, together with an increase of bulk of from two to three times the original volume. This reduction to an impalpable powder is called "slaked lime" or "calcic hydrate," which forms with water an unctuous paste. This paste, in common with mortar, will not harden in the presence of water.

The advantage of using lime for purification, either alone or in combination with iron oxide, is the more complete removal from the gas of sulphur compounds and also the removal of carbonic acid, for which the oxide alone has no affinity (see table of Effect of CO_2 on Candle Power). The effect of CO_2 on illuminating gas can only be removed entirely by purification. Its removal causes a whiter, purer, and brighter light, which cannot be compensated for by increased enrichment or the addition of hydrocarbons. These advantages may be worth the additional cost in purification, even where lime is comparatively dear.

It is, however, claimed by advocates of iron oxide that American coal-gas contains but few sulphurous compounds other than sulphureted hydrogen, and that this latter is the only needful impurity to remove, and can be accomplished entirely by the use of oxide. It is also claimed that while lime removes the CO_2 it also mechanically separates from the gas certain of the heavier hydrocarbons, thereby neutralizing the benefit derived by its removal.

The question reduces itself largely to a basis of cost of materials and as to whether additional oil be used to make up the loss, or whether a saving can be effected by the removal of the CO_2, thereby increasing the efficiency of a less amount of enrichment used.

Calculations.—As to the purifying capacity of lime for CO_2, the theory is as follows: Assuming a bushel of unslaked lime to weigh 80 lbs. and to contain 90 per cent. of CaO, one bushel of lime would therefore contain about 72 lbs. of pure CaO. Slaking this lime the following reaction would take place;

$$CaO+H_2O=Ca(OH)_2,$$

or calcic hydrate. Since the atomic weight of Ca is 40, O is 16, H being 1, the equation would represent $(40+16)+(2+16)=(40+17\times2)=74$. Therefore, 56 lbs. of CaO will make 74 lbs. of $Ca(OH)_2$, and 72 lbs. of CaO will make 95.11 lbs. of $Ca(OH)_2$. The reaction equation between slaked lime and CO_2 is

$$\begin{array}{ccccccc} Ca(OH)_2 & + & CO_2 & = & CaCO_3 & + & H_2O \\ 74 & + & 44 & = & 100 & + & 18 \end{array}$$

We see that 74 lbs. of $Ca(OH)_2$ will combine with 44 lbs. of CO_2, therefore 95.11 lbs. of $Ca(OH)_2$ will combine with 56.55 lbs. of CO_2. Dry CO_2 at 60° F. and 30 in. barometer weighs 1 lb. for each 8.595 cubic feet, so that $56.55\times8.595=486.047$ cubic feet.

Supposing gas to contain 3 per cent. of CO_2 or 30 cubic feet per 1000 cubic feet of the gas, we have 486.047 divided by 30, or 16.202 cubic feet multiplied by 1000, equaling 16,202 cubic feet, the maximum amount of gas with which the calcic oxide in one bushel of lime, as aforesaid, will theoretically combine. Of course, under working conditions, this combination would be exceedingly less complete.

On the other hand, the maximum amount of sulphureted hydrogen which can be removed from gas (theoretically) can be calculated as follows: Suppose a bushel of the purifying material to contain an amount of $Fe_2O_3.H_2O$ equivalent to a weight of 25 lbs. of iron, and assuming that there is no oxygen present in the gas, the proportions would be as follows: Of the $Fe_2O_3.H_2O$ the atomic weights are Fe = 56, O = 16, and H = 1. The molecule of the oxide will therefore contain $(56\times2)+(16\times3)+(1\times2)+16=178$ parts by weight, of which 112 parts are iron and therefore 25 lbs. of iron will form $25\times\frac{178}{112}=39.7$ lbs. of ferric hydrate. The reaction given by Butterfield for the removal of H_2S from gas by this ferric hydrate is as follows:

$$Fe_2O_3.H_2O+3H_2S=Fe_2S_3+4H_2O;$$

$$Fe_2O_3.H_2O+3H_2S=2FeS+S+4H_2O.$$

The proportion between $Fe_2O_3.H_2O$ and H_2S is the same in both equations; the amount of H_2S absorbed by a given quantity of $Fe_2O_3.H_2O$ is the same, no matter which of the two above reactions may occur.

The atomic weight of S is 32; therefore, the weight of H being

one, the molecule $H_2S \times 3$, as in the equation, equals 3 $(2 \times 1 + 32)$, or 102 parts. Therefore, 178 atomic parts of $Fe_2O_3.H_2O$ will combine with 102 parts of H_2S, or 1 lb. will combine with 0.573 lbs., from which we derive that 39.7 lbs. of $Fe_2O_3.H_2O$ will combine with 22.748 lbs. of H_2S. Now, if 1 lb. of dry H_2S at 60° F. and 30 in. barometer occupied a volume of 11.1229 cubic feet, we conclude that 22.748 lbs. will correspond with 22.748×11.1229, or 253.02 cubic feet of H_2S.

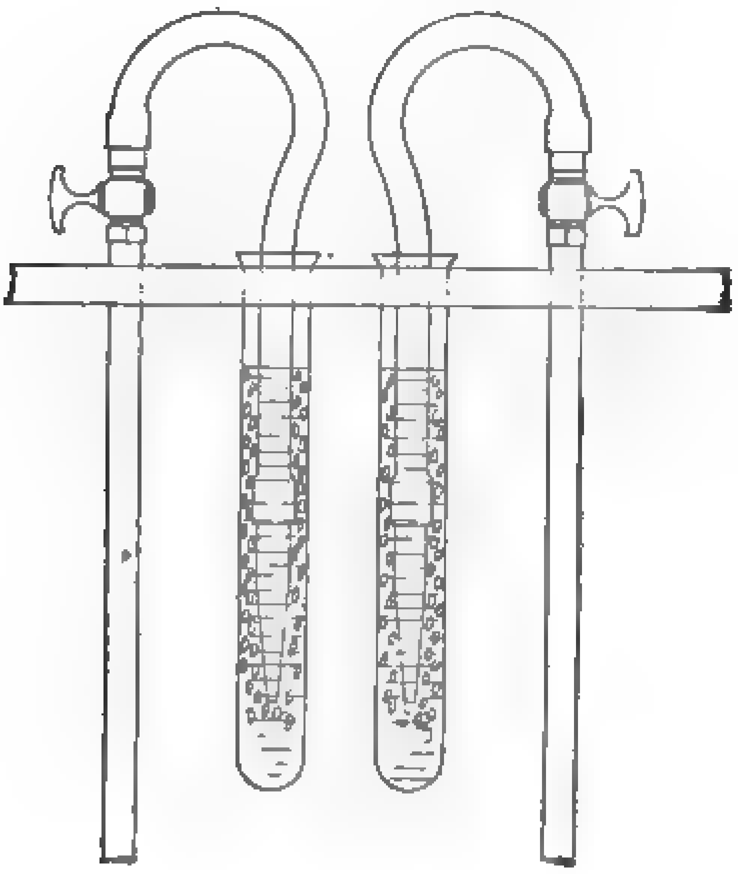
Assuming a gas, therefore, to contain 0.85 per cent. by volume of H_2S it will contain 8.5 cubic feet of H_2S per 1000 cubic feet of gas, or $253.02 \div 8.5$ equals 29.791, denoting that 29.791 cubic feet is the maximum amount of gas containing the said amount of H_2S that can be theoretically removed by chemical union with one bushel of the above-mentioned purifying material. But, as noted in the calculations for the theoretical purifying power of lime, these results cannot be nearly attained under working conditions.

Temperature.—It may be noted, however, that conditions of temperature have much to do with the combining power of both the lime and the oxide, as at a temperature below 30° F. both lime and ferric oxide are practically inactive with reference to H_2S, and above this temperature their capacities for combination increase more and more, until at a temperature of 100° to 120° F. the action becomes as complete as can be obtained under working conditions. It follows from this that purifying-houses, lime-rooms, and revivifying-sheds should always be maintained at a temperature not less than 60° F., and that concrete boxes built out of doors and other exposed purifiers should be properly heated with steam-coil, or the gas itself should be heated prior to entry therein.

Testing Oxide Boxes.—For determining whether the bed of oxide is doing service or not, Fig. 16, on the following page, illustrates an easy method. Byron E. Choller describes the arrangement thus: "It frequently happens that both inlet and outlet of a purifying-bed will show an equally foul test with lead paper, while the bed may yet be doing work. The cut shows how this condition may be ascertained: a pipe and stop-cock leading from each side of the bed, rubber tubes with glass nozzles of equal size attached, and a weak solution of permanganate of potash are all that are required. Put equal quantities of equal strength of the solution in the test-tubes, insert the glass tubes, and turn on the gas in both at the same time. Foul gas will make the solution clear almost immediately. If the bed is doing work, the inlet side will clear up quicker than the outlet side. Two or three grains, or perhaps less, of permanganate of potash to a quart of clean

water is sufficient. Keep the solution in a well-stoppered bottle, and do not make up too much at a time."

Judging from a few experiments, when it takes the outlet four or five times as long as it does the inlet to clear up by this method it is time to change the box, as in such case it would be taking out only about 20 per cent. of the sulphur in the gas.



SULPHUR TEST TUBE.

FIG. 16.—Comparison of Sulphur in Inlet and Outlet Gas.

Revivification.—This can be done while the gas is passing through the boxes for purification by admitting a small percentage of air or oxygen, 1½ per cent. to 0.5 per cent., with the gas; or air can be blown or sucked through the foul oxide after the box is turned off and opened; otherwise the oxide can be removed from the box and revivified elsewhere.

By revivification is meant the reduction of the iron-sulphur compounds again to active iron oxides or hydroxides; reactions are

$$2Fe_2S_3 + 3O_2 = 2Fe_2O_3 + 3S_2$$

or

$$12FeS + 9O_2 = 6Fe_2O_3 + 6S_2.$$

Oxide can generally be used until it has taken up 60 per cent. of sulphur by weight, although it generally becomes fouled by tar, etc., before this point is reached.

As to the proper handling of oxide for revivification, the Trustees of the American Gaslight Association have to say as follows:

"As probably no two samples of iron oxide (the words being used to denote a purifying material in which the active agent is hydrated ferric oxide) are exactly alike, it is impossible to lay down hard-and-fast rules that will apply in all cases. But there is one truth that must always be borne in mind and acted upon to secure the best results; this is, that revivification will be the more rapid and complete the higher (within reasonable limits) the temperature of the oxide. Therefore, the treatment should be such as to retain, as far as possible, in the material all the heat generated by the chemical action that occurs, provided, of course, that this heat is not excessive.

"At a works using oxide purchased from three different firms, the following method of handling during revivification was found to give the best results: As the oxide was removed from the box it was thrown on to the revivifying-floor, beneath the box, into heaps, each about 8 feet high, and allowed to remain in these heaps until it was thoroughly heated, the length of time required for the attainment of this result varying from one to two hours for fresh, active oxide to forty-nine hours or more for that nearly spent, or sluggish from any other causes. When hot it was taken from the heap and placed on the floor in long ridges, whose cross-section was approximately an equilateral triangle with 24-inch sides. Spaces were left between the ridges, and as the oxide on the two exposed faces revivified, as shown by its change in color, it was scraped down into these spaces until the whole batch was spread out in a layer, with a uniform depth of about 9 to 10 in. It was then turned over with shovels, care being taken to have it really *turned* and the material that had been on the bottom placed on top, instead of the whole mass being merely shoveled to one side, which is very often all that the so-called turning over amounts to. By this time it was usually thoroughly revivified. If not, it was again turned over as often as necessary. When revivified the batch was piled in a heap about 6 feet high and 4 to 6 feet wide to remain until it was put back into the box in due course. Sufficient time was allowed to elapse between each handling for complete revivification of the top layer of oxide. During the operation the oxide was then wet, unless it became excessively heated or so dry that there was a loss and a nuisance in handling, owing to the dust arising from it. By thus keeping

the oxide as dry as possible, all the heat produced by chemical action was made available for maintaining the temperature of the material and thus promoting complete revivification, instead of being used up in vaporizing added water.

"In handling batches of fresh oxide care must be taken to prevent their becoming so highly heated as to ignite the sulphur and shavings contained in them. Even in such cases, however, it is better to allow the oxide to stay in heaps. Since less surface is exposed to the air in this way, the liability of ignition is less, and if it does occur the fire can be more readily extinguished by the use of water. Such heaps should be examined at frequent intervals and any tendency to fire be attended to. Ignition cannot occur with wet oxide until the water has been practically all evaporated, so wetting the oxide will always prevent it. But as it also retards revivification it should only be resorted to in cases of necessity. Spreading the oxide out in layers and turning it constantly will also cool it.

"If a batch of oxide does not heat and revivify properly when handled as above, and its record shows that it is not yet saturated with sulphur, it can sometimes be brought into good condition again by being exposed out of doors in the sun during the warm weather, the sun imparting the heat necessary to start and maintain the revivification; or the batch can be heated artificially.

"Another method of revivification consists in placing the oxide, when taken from the heaps, on a platform of purifier-trays, supported about a foot above the floor of the revivifying-room in such a way as to permit a free circulation of air underneath the whole bed, the oxide being spread in a layer 24 to 30 inches deep. When using such a platform revivification takes place on the bottom as well as at the top of the layer, proceeding faster on the bottom. When the batch is turned, the oxide, still foul, should be put on the trays, and the oxide that has revivified either piled to one side or placed on top of the foul oxide. If this method is used with active oxide great care will be necessary to prevent firing, as revivification proceeds very rapidly, owing to the fact that air passes up through the oxide instead of merely being in contact with it."

It is generally the custom in slaking lime at works to reduce the lime to a sort of paste which will neither adhere to the fingers when suspended from them nor yet fall in a granular powder. It is probable, however, that this is hardly sufficient moisture, and it is better to add enough water to bring the lime to a homogeneous mass. This mass should be allowed to lie over some hours and then be worked over to rid it from lumps.

The tendency of all gas-engineering points toward revivifi-

cation *in situ.* This can be best accomplished by the admission of air in a fixed ratio (under 3 per cent.) with the gas at the inlet of the purifiers, which is easily arranged by belting a forge-blower

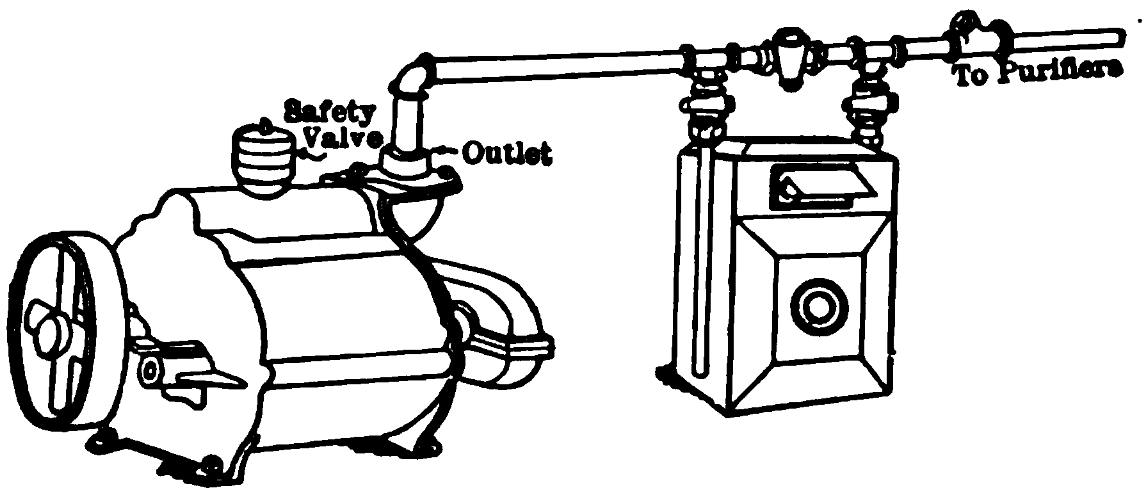


FIG. 17.—Revivifying *in situ.*

or one of the Connelly compressors direct to the shaft of the exhauster (Fig. 17).

LOSS BY IN SITU PURIFICATION.

Air Admitted, Per Cent.	Loss in Candle Power, Per Cent.
1.0	2.0
1.2	2.3
1.4	2.6
1.6	3.0
1.9	3.6
2.1	3.9
2.3	4.3
2.5	4.8

Removal of Traces.—It must be noticed in all forms of purification that the elimination of impurities, being chemical, can occur only where there is an intimate union and thorough contact of the gas with the material used. Should any tar or oily matter be allowed to come in contact with the purifying material, it will form a coating or insulation which will tend to prevent chemical action from taking place, besides fouling the material and causing it to solidify and coke, thereby producing back pressure. It is of enormous advantage to remove such substances as completely as possible before bringing them in contact with the purifying material, to which end the gas should first be passed through a bed of shavings or coke-breeze (oak-wood shavings should never be used for any purifying purpose, because of the tannic acid contained), forming a filter, which

material should be changed immediately as soon as it becomes saturated. In extreme cases a P. & A. condenser may be used or some device of baffle-plates, in which the tar and oil molecules carried along in suspension impinge and drain away by gravity.

Some such device will be found a great economy in works, as it has been the experience of the writer from a number of tests that the oxide or lime in the first boxes of the purifying series almost invariably become so foul as to become useless long before its combining affinity has ceased, and that by the use of proper extractors or filters the life of these materials will be indefinitely prolonged.

In addition to the injury done purifying material by small portions of heavy tar and oil, carried over in suspense by the gas, and for which there should be mechanical separation, tarry vapors are likewise a great menace not only to the material itself, but to the subsequent features of distribution, such as mains, services, the drums of meters, the cocks of fixtures, and especially the tips of burners and Welsbach mantles and appliances.

The simplest method of breaking up these vapors consists in placing a layer of chips and shavings or coke-breeze on the lowest tier of the trays of each purifying-box, so that when a box becomes the first in the series the gas passes through this filter, and the vapors are filtered out before the material in the upper portion of the box is reached. It is, however, better, where possible, to have one box or other vessel retained solely for the use of such scrubbing and containing several thick layers of wood chips, sawdust, and shavings or breeze. This box should invariably be the first in the purifying series, and this arrangement has the advantage that it can be easily determined as to the time when complete saturation of its material takes place, after which time it very imperfectly filters out the passing vapors. A discussion of the subject will be found in the Proceedings of the American Gaslight Association, Vol. 15, pp. 142 to 147, and can be read to some advantage.

A gas is said to be saturated with vapor at a certain temperature and pressure when it contains the full amount of vapor that it can carry under these conditions. Any change in these conditions will change its point of saturation, thereby causing it to carry more or less vapor or moisture. Also, when a gas is so saturated it cannot be made to take up any more vapor unless these conditions be altered. At any given temperature and pressure a definite quantity of a given vapor is required to saturate a gas, and this quantity is invariably the same under the same conditions. This is called the saturation- or dew-point.

Analysis for Total Sulphur.—The following excellent system was described before the American Gaslight Association by W. B.

Calkins of St. Louis, Mo.: The method depends upon the well-known chemical fact that sulphur compounds, such as carbon bisulphide, mercaptan, and other organic forms, break up and form H_2S when mixed with free hydrogen and passed over heated platinized asbestos or pumice.

After the sulphur compounds have been changed to the form of H_2S, it is a very simple matter to precipitate the sulphur in some form easily weighed or titrated, and the per cent. of sulphur figured back as grains of total sulphur per 100 cubic feet of gas.

In order to have the analysis as rapid as possible, gravimetric methods were not considered, but the well-known titration method with a standard iodine solution was used.

The iodine method used is one commonly employed for rapid determination of sulphur in pig iron and steel, and consists in absorbing or precipitating the sulphur evolved from the iron or steel as H_2S in solutions of NaOH, KOH, or in an ammoniacal solution of cadmium or zinc chloride. The use of the two latter are to be preferred on account of the sulphur being in a visible form (CdS or ZnS), and one which is not liable to alteration on standing.

The reaction that takes place when H_2S is run into a strongly ammoniacal solution of cadmium chloride is as follows:

$$H_2S + CdCl_2 + 2NH_4OH = CdS + 2NH_4Cl + 2H_2O.$$

Now if the solution containing the precipitate of CdS is diluted with a *large volume* of cold, distilled water and a sufficient quantity of HCl added, H_2S is set free by the following reactions:

$$CdS + 2HCl = H_2S + CdCl_2.$$

A considerable excess of HCl is needed to effect a complete reaction, and the volume of water present *must* be large and cold in order to prevent the escape of any H_2S.

The solution of H_2S in water is now titrated with a standard iodine solution, using a little fresh starch solution as an indicator; the reaction is as follows:

$$H_2S + 2I = 2HI + S.$$

The least excess of iodine is shown by the intense blue color (iodide of starch) that is instantly formed as soon as the reaction is complete. The solutions needed are a standard solution of iodine, a fresh, clear solution of starch, and a strongly ammoniacal solution of cadmium or zinc chloride.

No arbitrary standard solution of iodine is needed, but one can be made up and standardized to suit local conditions, the preparation and standardizing of which can be found fully explained in any good book on quantitative analysis.

For the cadmium chloride solution a good strength for the stock bottle is made by dissolving four grains of cadmium chloride in 100 c.c. of water, and when dissolved add an equal volume of strong, chemically pure ammonia.

The platinized asbestos for filling the combustion-tube is easily prepared: Take ¼ pound of clean asbestos wool, free from sulphur, wash in 2 ounces of a 5 per cent. solution of platinum chloride, then dry, place in a large evaporating dish, separate the wool, moisten evenly with alcohol and ignite; this forms a coating of platinum black over the wool fibers. The wool must now be strongly heated in order to drive off any free acid.

The apparatus needed for this method consists in a good meter, one that will accurately measure $\frac{1}{60}$ of a cubic foot (or, in place of this, a good meter-prover can be used, and the sample of gas it contains can be taken as representing the average gas made for several hours); a small 15-burner combustion furnace; some good Jena glass combustion-tubing 30 in. long, or a flanged porcelain tube glazed inside, 30 in. long and ½ in. inside diameter; about four plain, ringed-neck glass cylinders 9 in. high, to hold about 150 c.c., with 2-holed rubber stoppers to fit; one small brass aspirator, filter-pump, and several feet of good glass and pure gum rubber tubing for making connections.

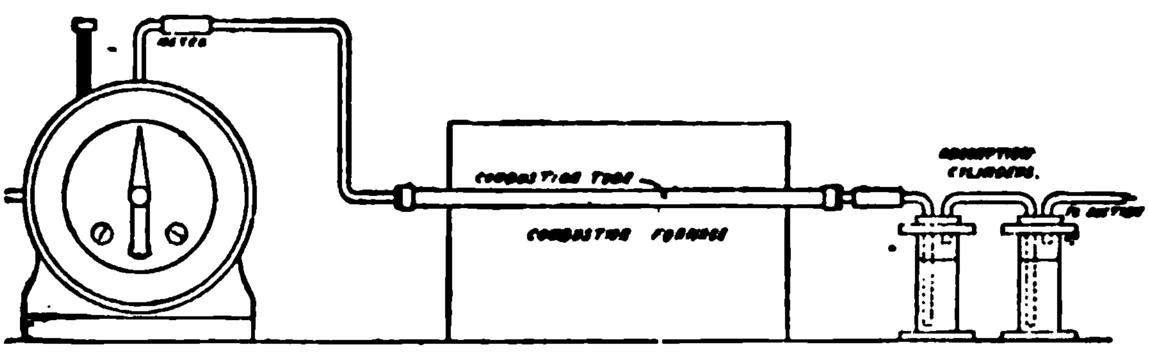


FIG. 18.—Analysis for Total Sulphur Apparatus.

Before starting the test the meter and combustion-tube must be filled full of the gas to be tested and the gas shut off, then the combustion furnace heated up, slowly at first so as not to crack the combustion-tube, until the tube is a dull red (about 1000° to 1200°); now read the meter, turn on the gas, and by means of the aspirating-pump draw the gas through the loosely packed combustion-tube, which is connected to a delivery-tube which reaches almost to the bottom of the first receiving cylinder, then through a second receiving cylinder and out through the aspirating-pump,

which is attached to the water service. By means of the pump the gas can be drawn at any required speed through the apparatus, but faster than ½ foot an hour is liable to bubble the cadmium chloride solution out of the first cylinder into the second. The second cylinder is used as a guard in case any H_2S might pass the first one.

Both cylinders are filled with a solution of the same strength; 3 c.c. of the strong cadmium solution is first added to each cylinder, then about 10 c.c. of strong ammonia, after which the cylinders are filled with distilled water to a depth of about 7 in.

When the required volume of gas has been passed, the meter and aspirating-pump are shut off, the cylinders disconnected and washed out with a large volume of cold water into a deep cylindrical beaker, a few cubic centimeters of starch solution are added, and then a large excess of concentrated chemically pure HCl, and, without much stirring at first, the whole titrated with the iodine solution as rapidly as possible, adding it until the last drop changes the opalescent liquid to a deep blue, not disappearing on standing for two or three minutes.

There must be no delay in titrating, for if the solution containing the CdS is allowed to stand it will lose H_2S, or the sulphide may oxidize.

Another method is to quickly filter off the flocculent precipitated CdS, the filter and precipitate placed in a deep beaker containing a large volume of cold water, the HCl and starch solutions added, then titrating. This avoids the presence of a large amount of ammonia salts and any hydrocarbons absorbed in the liquid with which it has been claimed the iodine reacts slightly.

The combustion-tube must be loosely packed from time to time with fresh platinized asbestos, for the old will gradually be coated with carbon and the tube stopped up.

To prove that the chemical reaction was complete, known quantities of chemically pure carbon bisulphide and mercaptan were vaporized with pure hydrogen gas. This mixture was passed through the apparatus, the H_2S precipitated with cadmium chloride, and the amount of sulphur found agreed with the per cent. of sulphur contained in the organic sulphur compounds.

Other tests for accuracy were made by comparing results obtained from the same sample of gas, by determining the per cent. of total sulphur present, first with the London Gas Referees' sulphur apparatus, then by the combustion method, and the results agree very closely. The following are a few of the results:

SULPHUR IN GAS PER ONE HUNDRED CUBIC FEET.

	Referees' Method.	Combustion Method.
1..........	14.512	14.530
2..........	16.224	16.320
3..........	15.820	15.980
4..........	18.256	18.724

Correction for temperature and pressure must be made as in any gas analysis.

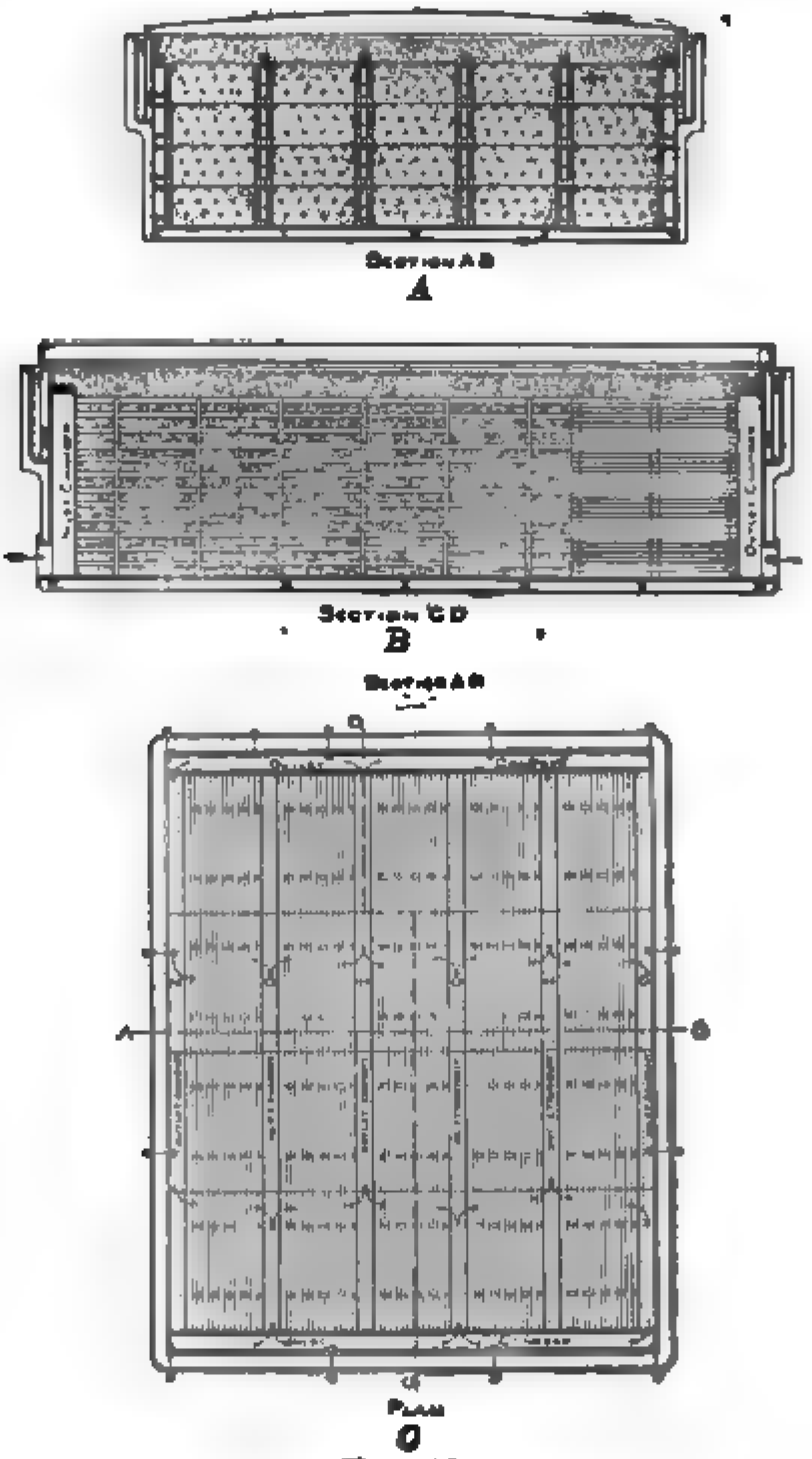
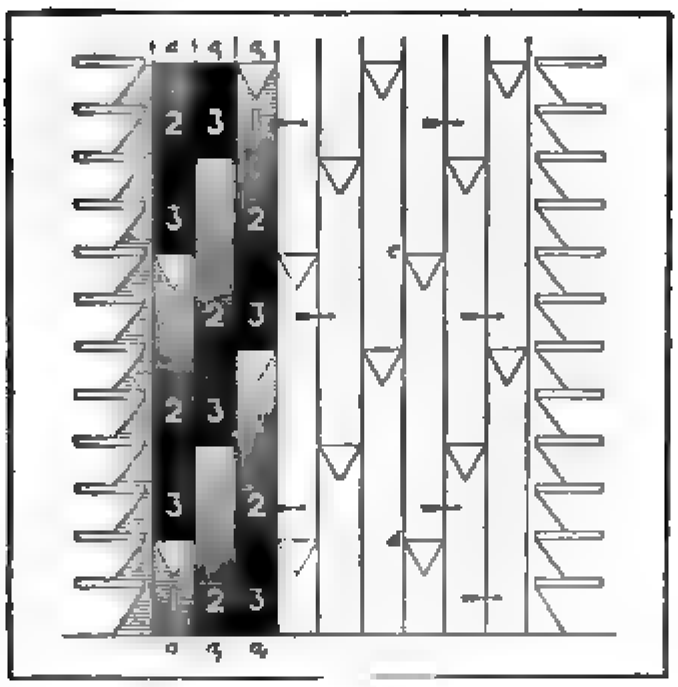


Fig. 19.



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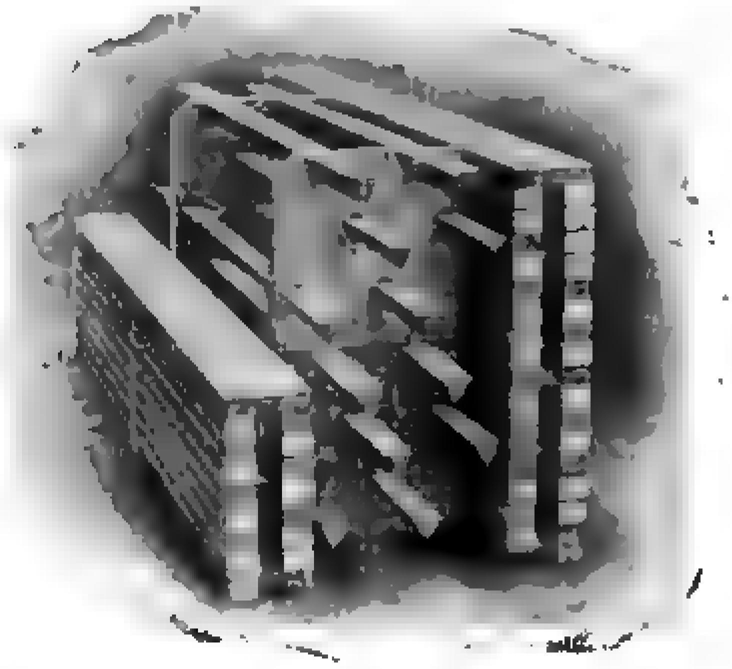


E

FIG. 20.

The accompanying cuts *A*, *B*, *C*, *D* (Figs. 19 and 20), show the arrangement of a Purifying-box equipped with the Jaeger Grid, while cut *E* shows a section of the Grid itself. As will be seen the object of the Grid is to increase the intimacy of the circulation, and obtain for the box higher cubical capacity and greater oxide efficiency.

CHAPTER VIII.

EXHAUSTERS.

THE trustees of the American Gaslight Association give the following calculation for obtaining the horse-power necessary to handle a given quantity of gas, pumping it with an exhauster. As an example of their calculation, they take the pumping of 17,000 cubic feet of gas per hour, with an inlet pressure of 1.1 in. against an outlet pressure or head of 12 in.

"**Power Required.**—The term horse-power is used to indicate the rate at which mechanical work is done and denotes the performance of 33,000 foot-pounds of work per minute; that is, the raising of a weight of 33,000 pounds through a height of one foot, or the overcoming of a resistance of 33,000 pounds through a space of one foot. The horse-power required to pump gas can therefore be calculated by dividing the product of the resistance overcome and the space through which it is overcome in a minute by 33,000, the resistance being measured in pounds pressure and the space in feet. The resistance is determined by the net pressure against which the exhauster is working, that is, by the difference between the pressure at the outlet and that at the inlet of the exhauster. The space can be taken as the number of cubic feet of gas pumped in a minute, without any reference to the actual velocity with which the gas passes through the outlet-pipe, since with a given outlet pressure the total resistance against which the exhauster is working varies directly as the area of the outlet-pipe, while the velocity of the gas, or the space passed through in the unit of time, varies (when the same quantity is pumped per minute) inversely as the area of the outlet-pipe, and therefore the product of the total resistance and the space passed through will always be equal to the product obtained by multiplying the resistance per square foot by the number of cubic feet of gas pumped in the unit of time. The gas pressure is usually given in terms of the height in inches of the water column which it will balance; to convert this to pounds per square foot,

it is necessary to multiply it by the weight of a column or water 1 sq. ft. in area and 1 in. high. A cubic foot of water weighs 62.5 pounds; therefore a column of water 12 in. high exerts a pressure of 62.5 pounds per sq. ft., and a column 1 in. high will exert a pressure $62.5 \div 12 = 5.2$ pounds per sq. ft. The horse-power required for the actual work of pumping the gas can therefore be determined by multiplying the number of cubic feet pumped per minute by the product obtained by multiplying the net pressure in inches of water by 5.2 (which gives the pressure in pounds per square foot against which the exhauster is working) and dividing the final product by 33,000. Putting this rule into the shape of a formula, we have

$$\text{H.P.} = \frac{5.2VH}{33{,}000},$$

in which V = number of cubic feet of gas pumped per minute, and
H = the difference between the outlet and the inlet pressure in inches of water.

In the present problem

$$V = \frac{17{,}000}{60} = 283.33 \text{ cu. ft.},$$

and

$$H = 12 - 0.1 = 11.9 \text{ in.},$$

$$\text{H.P.} = \frac{283.33 \times 11.9 \times 5.2}{33{,}000}$$

$$= \frac{17532.46}{33{,}000} = 0.531 \text{ h.p.}$$

"Therefore the horse-power required for pumping the gas, without taking into consideration the friction of the exhauster or any other losses of power in the machinery, is 0.558 h.p.

"George J. Roberts, from actual tests on pumping gas into a holder, deduced the following formula for an exhauster of the Wilbraham type:

$$\text{H.P.} = 0.00511HV;$$

H = the net pressure in inches pumped against, and
V = thousands of cubic feet pumped per hour.

"Substituting the value of H and V in the present problem, we have

$$\text{H.P.} = 0.00511 \times 11.9 \times 17 = 1.03.$$

"So that the total horse-power required according to this formula is nearly double that required for pumping the gas." Or, in other words, the efficiency of the engine and exhauster when working at this rate is only about 50 per cent.

Installation.—In installing the exhauster, solid masonry should invariably be used, no other material being as good for a foundation. The bed-plate is bolted directly by bed-bolts to this, and without any intervening wooden structure, which may have a tendency to decay and increase vibration. One of the most common causes of trouble is due to the springing of the outlet and inlet connections into place to correct the fitting, the latter not being true. This tension has a tendency toward causing knocking and binding of the working parts of the machine. The connections should invariably be square and true, and so supported as to relieve the flanges of the exhauster not only of any torsion, but of their own weight.

Internal heating, which is difficult to discover, occasioned by the thrust of the crank-shaft of the engine, is another contingency with exhausters. This is frequently caused by the set of the machine not being perfectly level and can usually be detected and the cause located by taking out the bolts of the coupling, an imperfect alignment being indicated by the springing of the coupling flanges. Misalignment of the parts of the bed-plate is indicated by a separation of these parts, while a thrust of the crank-shaft is shown by the binding of the flanges against each other. This can be remedied by forcing the engine to or from the exhauster, re-reaming the dowel-holes and driving in fresh dowels.

Operation.—It sometimes happens, after an exhauster is shut down, that it is "tar-bound." This is overcome by the introduction of benzine or kerosene through the sight-feed oilers, placed at the top of the exhauster case.

An exhauster should be as carefully kept up as any other form of a steam-engine. The first and most important point is that of cleanliness, which cannot be overrated, all excess of tar, oil, and dirt being kept away from the governor and other working parts. The adjustments should be examined daily, and once or twice a season an indicator diagram should be taken from the engine, to note if valves are properly set. The machine should have constant attention with regard to oiling, and the engineer should by regular inspection note that the oil-cups are replenished and are emptying equally. The packing of exhausters is especially prone to become hard and to grind the axle-shafts and other working parts. It should be removed as often as inspection shows to be necessary, perhaps once in three

months. It is needless to say that all bearings must be properly kept up, especially those supporting the impellers. The gears may best be lubricated with a mixture of grease of good quality or graphite.

Losses.—The power lost in friction in an exhauster will average between 7 and 9 per cent. of the total amount applied to the machine during the period of full load. It is, however, very nearly constant and varies but slightly between the maximum and minimum load. The slip is also a constant quantity under any one pressure, the total slip per minute being about the same, whether the machine is running fast or slow. In a comparative test, where the air delivered was measured by meter, and in what is known as the "closed discharge test," the results disclosed little or no discrepancy. The "closed discharge test" is apparently the more accurate, and consists in closing the valve on the discharge side of the machine, when the machine is then operated at such speed as to maintain the pressure desired. The slip is then equal to the displacement of the machine per revolution, multiplied by the number of revolutions per minute, to maintain the pressure. It is, of course, understood that the valves in the connection should be perfectly tight.

As to thermal loss, there is but little known. Air compressed to three pounds, according to the test of Geo. C. Hicks, Jr., shows an increase in temperature of 18 deg. F. The specific heat at constant pressure is about 0.2377; hence it will appear that the loss would be extremely small in actual units of work. For instance, the maximum loss, due to the difference between isothermal and adiabatic compression in air compressed to five pounds, is only about 4.5 per cent. In the case of the rotary machine, at least, the compression is adiabatic or very nearly so.

Where the steam-piping is small, or the steam pressure variable, it is advisable to interpose a regulating-valve immediately before the steam-inlet of the exhauster.

In the use of any positive-pressure gas-pump (especially where there is no holder on the line) and in the connections of an exhauster, a relief-valve or seal-pot should be placed upon the pressure side, its overflow or "escape" being connected to a blow-back or by-pass, leading into one of the holders or the suction side of the pump or exhauster.

In the first case this is to prevent excessive "building up" of pressure in the pipe-line; in the case of the latter, or exhauster, the arrangement is to prevent the "blowing" of the purifying-boxes; in this instance the relief-valve or seal for blow-back must be adjusted considerably under the seal capacity of the boxes, securing thereby a margin of safety.

Few engineers are aware of the loss, amounting to a material item, occurring through the blowing of the boxes and the consequent escape and loss of gas, to say nothing of the tremendous danger to life and property.

Slip.—According to Mr. Geo. C. Hicks, Jr., "the slip of a rotary blower should vary as the square root of the pressure, speed being constant, and inversely as the speed, the pressure being constant; directly as the clearance; directly as the square root of the reciprocal of the specific gravity, and directly as the square root of the ratio of the absolute temperatures."

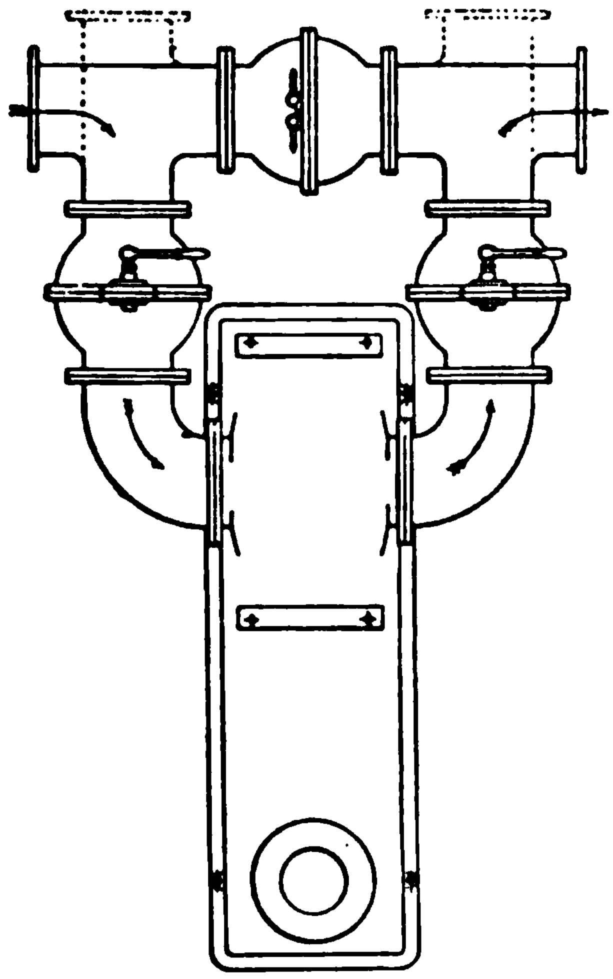


FIG. 21. — Exhauster By-pass and Connections.

For continuous-contact impellers the law of flow of gas through an orifice is very close to actual results. It will, therefore, appear that to attain high efficiency in a machine it should be as nearly as possible of such size as will warrant approximately its maximum rate of speed during service. For the increase of volume of gas passed in a given time decreases the per cent. of slip in inverse ratio as the increase of revolutions per minute. This is generally true up to the safe speed limit.

The slip also varies directly as the square inches of the opening of clearance, which should therefore be kept down to the lowest margin compatible with safety. This is especially true with heavy-duty exhausters (operating over 3 to 4 lbs. pressure).

In low-pressure work the slip may be said to vary, inversely with the speed, from 1 to 20 per cent. Temperature affects the slip only, as has been stated, as proportional to the square root of the ratio of absolute temperature, and has nothing to do with the shrinkage in volume due to a decrease in gas temperature.

Specific gravity affects the slip, as above stated, as the square root of the reciprocal, as, for instance, gas at 0.5 gravity would give a slip 1.41 times as much as air under similar conditions.

The friction losses in an exhauster are practically those entailed by the bearings and the gears.

The pressure of the gears should be plus in a downward direction, in order to prevent a "floating shaft," as such an arrangement is hard to keep in alignment and tends toward hot bearings.

In this connection we may say that much depends upon the accuracy of cutting and keying of the impeller-gears, the juxtaposition of the impellers, the conditions of clearance, and the general alignment subject to such accuracy. For low-pressure machines (1 to 2 lbs.) single gears with double outboard bearings are preferable, while with the heavy-duty machines double gears with outboard bearings give better satisfaction. The advantage of the outboard bearing is to distribute the strain upon the machine and furnish double- instead of single-bearing surface, besides stiffening the entire apparatus.

Horizontal machines are, moreover, stiffer and better adapted to heavy duty than the vertical type. The double outboard bearings mentioned should be invariably specified, their cases in the instance of high pressures being approximately 2.25 times the gear diameter in length, and a bore, say, 1.65 times the gear diameter; for light duty (say 1 or 2 lbs.) 1.5 times the gear diameter will be sufficient.

The driving of exhausters belongs to three classes, viz., belt or rope drive, pinion gear and silent chain, and "direct connection." For the first the belt pull should average about 75 lbs. and have a speed of between 3000 and 4000 feet per minute. At this figure the loss of power should not exceed over 3 per cent. Counterbelting should be permitted only on very light service loads. For this class of drive outboard bearings are especially necessary to maintain rigidity.

The silent chain should give an efficiency of about 98 per cent., gear transmission 95 per cent. These methods are especially necessary in connection with turbine or high-speed motive power.

Where direct connection is used the flexible connection is decidedly advisable, and is absolutely essential in heavy-duty machines having the service of over 4 lbs. This is by reason of the facility with which alignment between the exhauster and prime mover may be maintained, this being almost impossible where the connection is rigid.

Of late years small exhausters have come into frequent use in connection with "booster" or high-pressure feed-lines, also for long-distance transmission.

Such service rarely exceeds a maximum of over 4 lbs. discharge duty with 8 to 12 inches water pressure on the suction end. Under such conditions the total losses (principally slip and friction) will hardly exceed a maximum of 15 per cent., 7 or 8 per cent. being the average. As this service must be executed under variable conditions of speed, the prime mover should be designed for very sympathetic hand regulation.

The highest efficiency of this service is at about 5 lbs. duty, where the minimum efficiency is possibly not below 80 per cent.

For heavier duty, however, say 8 to 10 lbs. or over, its commercial efficiency ceases, and some other form of condenser or pump should be used. In emergency, however, for service of this kind two or more exhausters may be connected in tandem with a fair degree of efficiency.

In summing up the losses due to slip, Mr. Geo. C. Hicks, Jr., an expert in the matter, says:

"Losses due to slip are dependent on two principal factors, pressure and speed. The curves shown for constant speed and varying pressure cover a range of pressure from 22 in. of water to 122.1 and a loss due to slip within the ranges of ordinary operation of from 30 per cent. maximum to 1 per cent. minimum.

"In gas-exhauster work, say at a maximum pressure of 22.5 in. of water, the slip ranges from 1 per cent. for various speeds on an air basis. Modifying this for gas by multiplying by the square root of the reciprocal of the specific gravity or 1.41, the resultant loss is from 1.41 per cent. to 28 per cent., or an average slip of 14.75 per cent. for speeds ranging from 50 to 170 r.p.m.

"For pumping clean gas, where it is possible to use a nearly constant speed, it is clearly advisable to select a machine to operate at its highest safe speed and thus get an efficiency of 81 per cent. according to these tests, which were made on a machine not specially built for this service. Later results show an efficiency of 85 per cent. under 5 lbs. pressure. The loss due to friction ranges from 1 to 15.5 per cent. and shows an average of about 7 per cent. at 130 and 170 r.p.m., and 5.4 per cent. at 110 r.p.m.; so it is safe to assume 7 per cent. as an average friction load. This gives for gas-exhauster work an average efficiency of power applied to the shaft of 85.26 per cent. times 93 per cent., or nearly 80 per cent., as the useful effort of the power applied to the shaft. For high-pressure pumping we have 81 per cent. multiplied by 93 per cent., or 75.3 total, and on a basis of 85 per cent. volumetric efficiency a total efficiency of 80 per cent. The loss due to temperature is not chargeable to the machine construction, as it is simply a shrinkage proposition and brings one to much the same set of formulas as those used in estimating condenser surfaces. Not considering the latent heat of the vapors, an approximate method is to consider the volumes as proportional to their absolute temperatures.

"The increased slip, as stated before, would be proportional to the square root of the ratio of the absolute temperature. Assuming a rise to 140 deg. from 60 deg., the slip would be multiplied by the ratio 1.07; this 14 per cent. slip times 1.07 equals about 15 per cent., or an increase of only 1 per cent. due to a rise in temperature of 80 deg. The heat of compression at 10 lbs.

would raise air at 60 deg. up to 145, affecting the slip about the same amount 1 per cent. The heating effect on the incoming air would be slight and I do not believe would result in an appreciable loss in volume delivered. The results stated before include all these losses, and these points are brought up to show there is no need to consider these items as separate losses, at least at the comparatively low pressure used in rotary machines, and as a matter of fact it is probable that, the case expansion being less than the impeller expansion, the clearance is reduced and the slip decreased to some extent, probably enough to offset the additional slip due to the decrease in the density of the gas."

Air-compressor Capacity.—Capacities of air-compressors in cu. ft. of free air per minute in common practice are usually calculated by multiplying the area of the intake cylinder by the feet of piston travel per minute. The free air capacity divided by the number of atmospheres will give the volume of compressed air per minute. To ascertain the number of atmospheres at any given pressure, add 14.7 lbs. to the gage pressure, divide this sum by 14.7, and the result will be the number of atmospheres.

This calculation, however, is merely theoretical, and the results derived are never attained in actual practice, even with compressors of the very best design. Allowances should be made for various losses, the principal one being due to clearance spaces, but in machines of poor design and construction considerable losses occur through imperfect cooling, leakages past the piston and through the discharge-valves, insufficient area and improper working of inlet-valves, etc. There are compressors where the total losses run as high as 30 per cent., whereas 2.5 to 10 per cent. should be the maximum.

The altitude at which the compressor is to operate is an important factor, as it affects its capacity in direct ratio to the elevation. It will be seen, as the density of the atmosphere decreases with the altitude, a compressor at high altitude takes in less weight of air at each revolution. The air being taken in at the intake at a lower initial pressure, the earlier part of each stroke is occupied in compressing the air up to the normal pressure of 14.7 lbs., and the net capacity of the air-cylinder is thereby reduced. The power required to drive the same compressor is also less than at sea-level, but this decrease being in lesser ratio is not an offset.

Compressors to be used at high altitudes should have the steam- and air-cylinders properly proportioned to meet varying conditions. The first table on page 103, based on a compressor working at sea-level and discharging at a pressure of 70 lbs., indicates the variation of compressors at different altitudes.

TABLE OF SIZES, POWER, AND CAPACITIES OF ROOT'S GAS-EXHAUSTERS

No. of Exhauster.	Suction and Discharge Diameters.	Horse-power at Stated Speed.	Speed of Exhauster.	Displacement in Cu. Ft. per Revolution	Capacity per Hour in Cu. Ft., No Allowance for Shrinkage.
2	[illegible]	.75	200	.72	8,600
3	6	1.5	190	1 50	17,100
4	8	2 5	180	3.07	33,150
5	10	3.75	170	5 20	52,140
6	12	5.	160	8 20	78,720
7	16	7.50	150	12 43	111,840
8	16	11.	140	20	168,000
8½	20	15.5	130	29.	226,200
9	20	19.	120	37.25	268,200
9½	20	24.	110	50.	330,000
10	24	29.	100	63.10	378,600
10½	30	36.	95	83.	473,100
11	30	50.	90	116.	626,400
12	36	[illegible]	85	196.	999,600
14	42	115.	80	300.	1,444,000

NOTE.—Horse-power figured on basis of one pound per square inch, at speeds given in this table.

WILBRAHAM-GREEN GAS-EXHAUSTERS.

No.	Diameter of Connections, In.	Displacement per Revolution, Cubic Feet.	Revolutions per Minute.	Displacement per Hour, Cubic Feet.	Displacement per 24 Hours, Cubic Feet.	Revolutions per Minute.	Displacement per Hour, Cubic Feet.	Displacement per 24 Hours, Cubic Feet.
3	6	1½	100	9,000	216,000	150	13,950	334,800
4	8	3	100	18,000	432,000	150	27,000	648,000
5	10	5½	100	33,000	792,000	150	49,500	1,188,000
6	12	9	100	54,000	1,296,000	130	70,200	1,684,800
7	16	15	90	81,000	1,944,000	125	112,500	2,700,000
8A	16	22	90	118,800	2,851,000	125	165,000	3,960,000
9A	20	35	85	178,500	4,284,000	115	241,500	5,796,000
9B	20	45	75	202,500	4,860,000	110	297,000	7,128,000
9½	24	55	75	247,500	5,940,000	110	363,000	8,712,000
10	24	67	70	281,400	6,753,600	100	402,000	9,648,000
10½	30	85	70	357,000	8,568,000	100	510,000	12,240,000
11	30	112	70	470,400	11,289,600	100	672,000	16,128,000
8B	16	25	Special size					

The above volumes are the displacement of the exhausters at a moderate speed, without allowing anything for loss or shrinkage.

REVOLUTIONS OF FAN-WHEEL OF GIVEN DIAMETER NECESSARY TO MAINTAIN A GIVEN PRESSURE OVER AN AREA WHICH IS WITHIN THE CAPACITY OF THE FAN.

Diameter of Fan-wheel in Feet.	Pressure in Ounces per Square Inch.												
	⅛	¼	⅜	½	⅝	¾	⅞	1	1⅛	1¼	1⅜	1½	1¾
1	582	823	1007	1163	1300	1423	1537	1643	1742	1836	1925	2010	2170
1¼	466	658	806	930	1040	1139	1230	1314	1394	1469	1540	1608	1736
1½	388	549	672	775	867	949	1025	1095	1162	1224	1284	1340	1447
1¾	333	470	576	665	743	813	878	938	996	1049	1100	1149	1240
2	291	411	504	582	650	712	769	822	871	918	963	1005	1085
2¼	259	366	448	517	578	633	683	730	774	816	856	893	964
2½	233	329	403	465	520	570	615	657	697	734	770	804	868
2¾	212	300	366	423	473	518	559	597	634	668	700	731	789
3	194	274	336	388	433	475	513	548	581	612	642	670	723
3½	166	235	288	332	372	407	439	469	498	525	550	574	620
4	146	206	252	291	325	356	384	411	436	459	481	502	543
4½	120	183	224	258	289	316	342	365	387	408	428	447	482
5	118	164	202	232	260	285	308	329	349	367	385	402	434
5½	106	149	183	211	236	259	280	299	317	334	350	366	395
6	97	137	168	194	217	238	256	274	290	306	321	335	362
6½	90	126	155	179	200	219	236	253	268	282	296	309	334
7	83	117	144	166	186	203	220	235	249	262	275	287	310
7½	78	110	135	155	173	190	204	219	232	245	257	268	289
8	73	103	126	146	163	178	192	205	218	230	241	251	271
8½	69	97	119	137	153	167	181	194	205	216	226	236	255
9	65	92	112	129	144	158	171	183	194	204	214	223	241
9½	61	87	106	123	137	149	162	173	183	193	203	212	228
10	58	82	101	116	130	142	154	164	174	184	193	201	217
11	53	75	92	106	118	129	140	150	158	167	175	183	197
12	49	69	84	97	108	119	128	137	145	153	160	168	181
13	45	63	78	90	100	110	118	126	130	141	148	155	167
14	42	59	72	83	93	102	110	117	124	131	138	144	155
15	39	55	67	78	87	95	102	10	116	122	128	134	145

REVOLUTIONS OF FAN-WHEEL OF GIVEN DIAMETER NECESSARY TO MAINTAIN A GIVEN PRESSURE OVER AN AREA WHICH IS WITHIN THE CAPACITY OF THE FAN—(*Continued*).

Diameter of Fan-wheel in Feet.	Pressure in Ounces per Square Inch.												
	2	2½	3	3½	4	4½	5	5½	6	6½	7	7½	8
1	2319	2590	2834	3058	3265	3460	3643	3817	3992	4141	4293	4430	4580
1¼	1855	2072	2267	2446	2612	2798	2915	3054	3186	3313	3434	3551	3664
1½	1546	1727	1889	2039	2178	2307	2429	2545	2655	2761	2862	2960	3053
1¾	1325	1480	1619	1747	1866	1977	2082	2171	2276	2366	2453	2536	2617
2	1159	1295	1417	1529	1633	1730	1822	1900	1996	2070	2146	2219	2290
2¼	1030	1151	1259	1359	1451	1538	1619	1696	1770	1840	1908	1973	2035
2½	928	1036	1134	1223	1306	1384	1457	1527	1593	1656	1717	1776	1832
2¾	843	942	1030	1112	1188	1258	1325	1388	1448	1506	1561	1614	1665
3	773	863	945	1019	1089	1153	1215	1272	1328	1380	1431	1480	1527
3½	662	740	810	874	933	989	1041	1086	1138	1183	1226	1268	1308
4	580	647	708	764	816	865	911	954	996	1035	1073	1110	1145
4½	515	575	630	679	726	769	810	848	885	920	954	986	1018
5	464	518	567	612	653	692	720	763	796	828	859	888	916
5½	422	471	515	556	594	629	662	694	724	753	781	807	833
6	386	432	472	510	545	577	607	636	664	690	716	740	763
6½	357	398	436	470	502	532	561	587	613	637	661	683	705
7	331	370	405	437	466	494	520	543	569	592	613	634	654
7½	309	345	378	408	435	461	486	509	531	552	572	592	611
8	290	324	354	382	408	432	455	477	499	518	537	555	572
8½	273	305	333	360	384	407	429	449	469	487	505	522	539
9	258	288	315	340	363	384	405	424	443	460	477	493	509
9½	244	273	298	322	344	364	384	402	419	436	452	467	482
10	232	259	283	306	327	346	364	382	398	414	429	444	458
11	211	235	258	278	247	315	331	347	362	376	390	404	416
12	193	216	236	255	272	288	304	318	332	345	358	370	382
13	178	199	218	235	251	266	280	294	306	319	330	341	352
14	165	185	202	218	233	247	260	271	284	296	307	317	327
15	155	173	189	204	218	231	243	254	266	276	286	291	308

INFLUENCE OF ALTITUDE ON EFFICIENCY OF COMPRESSORS.

Altitude, Feet.	Barometric Pressure. Inches Mercury.	Barometric Pressure. Pounds per Square Inch.	Volumetric Efficiency of Compressors, Per Cent. Sea-level = 100.	Loss of Capacity, Per Cent.	Decreased Power Required, Per Cent.
1,000	28.88	14.20	97	3	1.8
2,000	27.80	13.67	93	7	3.5
3,000	26.76	13.16	90	10	5.2
4,000	25.76	12.67	87	13	6.9
5,000	24.79	12.20	84	16	8.5
6,000	23.86	11.73	81	19	10.1
7,000	22.97	11.30	78	22	11.6
8,000	22.11	10.87	76	24	13.1
9,000	21.29	10.46	73	27	44.6
10,000	20.49	10.07	70	30	16.1
11,000	19.72	9.70	68	32	17.6
12,000	18.98	9.34	65	35	19.1
13,000	18.27	8.98	83	37	20.6
14,000	17.59	8.65	60	40	22.1
15,000	16.93	8.32	58	42	23.5

The National Tube Co. has compiled the following table:

HORSE-POWER REQUIRED TO COMPRESS 100 CUBIC FEET FREE AIR FROM ATMOSPHERIC TO VARIOUS PRESSURES.

Gage Pressure, Pounds per Sq. In.	One-stage Compression, D.H.P.	Gage Pressure, Pounds per Sq. In.	Two-stage Compression, D.H.P.	Four-stage Compression, D.H.P.
10	3.60	60	11.70	10.80
15	5.03	80	13.70	12.50
20	6.28	100	15.40	14.20
25	7.42	200	21.20	18.75
30	8.47	300	24.50	21.80
35	9.42	400	27.70	24.00
40	10.30	500	29.75	25.90
45	11.14	600	31.70	27.50
50	11.90	700	33.50	28.90
55	12.67	800	34.90	30.00
60	13.41	900	36.30	31.00
70	14.72	1000	37.80	31.80
80	15.94	1200	39.70	33.30
90	17.06	1600	43.00	35.65
100	18.15	2000	45.50	37.80
		2500		39.06
		3000		40.15

D.H.P. = delivered horse-power at compressor cylinder.

Another table is as follows:

HORSE-POWER DEVELOPED IN COMPRESSING ONE CUBIC FOOT OF FREE AIR FROM ATMOSPHERIC PRESSURE (14.7 POUNDS) TO VARIOUS GAGE PRESSURES.

Initial Temperature of the Air in Each Cylinder Taken as 60° F.
Jacket Cooling Not Considered.

Gage Pressure.	Isothermal Compression.	Adiabatic Compression.			
		One Stage.	Two Stage.	Three Stage.	Four Stage.
10	0.0332	0.0358			
20	0.0551	0.0623			
30	0.0713	0.0842			
40	0.0842	0.1026			
50	0.0950	0.1187			
60	0.1042	0.1331			
70	0.1122	0.1465	0.128	0.122	0.119
80	0.1194	0.1585	0.137	0.131	0.127
90	0.1258	0.1695	0.146	0.139	0.135
100	0.1317	0.1800	0.154	0.146	0.142
125	0.1443	0.2036	0.171	0.161	0.157
150	0.1549	0.2244	0.186	0.174	0.169
200	0.1719	0.2600	0.210	0.196	0.190
300	0.1964	0.3164	0.247	0.229	0.220
400	0.2141	0.3613	0.276	0.253	0.242
500	0.2279	0.3889	0.299	0.272	0.260
600	0.2393	0.4318	0.318	0.288	0.275
700	0.2489	0.4608	0.335	0.302	0.289
800	0.2573	0.4873	0.349	0.314	0.299
900	0.2649	0.5114	0.363	0.325	0.310
1000	0.2720	0.5337	0.375	0.335	0.318
1200	0.2820	0.5742	0.397	0.353	0.333
1400	0.2924	0.6102	0.414	0.368	0.347
1600	0.3012	0.6427	0.432	0.381	0.359
1800	0.3087	0.6724	0.447	0.393	0.369
2000	0.3154	0.7003	0.460	0.403	0.379

NOTE.—The above values are for sea-level conditions only.

The loss in delivery of power in compressed air and gas (approximately) for single-stage compression will average perhaps 30 per cent., while that of two-stage compression will perhaps not exceed 17 per cent., while four-stage compression reduces the transmission loss to about 8 per cent.; as a stand-off against this economy, of course, is the additional initial power necessary to overcome the resistance and friction caused by additional valves, ports, coolers, etc., which may require an increase of from 10 to 15 per cent.

There is also a reduction of the unit strain upon the apparatus, all depending largely, however, for its efficiency upon the details

PRESSURE AND VOLUME OF COMPRESSED AIR (SHONE).

Pressure above Atmosphere.			Comparative Volume of Air after Compression Initial Volume = 1.		Temperature by Adiabatic Compression, that of the Free Air being 60° F	Rate of Compression Isothermally	Average Load against Compressing Piston, per Square Inch.	
			Isothermally	Adiabatically			Isothermally	Adiabatically.
Lbs. per Sq. In	Inches of Mercury	Feet of Water	Volume.	Volume.	Fahr.	Compression	Load.	Load.
1	2.041	2.31	0 936	0.954	70.04	1 0680	0.967	0.976
2	4 082	4.61	0 880	0 913	79 64	1.1361	1.876	1.910
3	6.123	6.92	0 831	0 876	88 84	1 2041	2 730	2 805
4	8.164	9.23	0 786	0 843	97 68	1 2721	3 538	3 664
5	10.205	11.54	0 746	0.812	106.18	1.3401	5.303	4.491
6	12 246	13.84	0 710	0 784	114 39	1.4081	5.031	5 288
7	14.287	16 15	0 677	0.758	122.32	1 4762	5 725	6 060
8	16 328	18 46	0 648	0 735	129 99	1.5442	6 387	6 806
9	18.369	20 76	0 620	0 713	137 43	1 6122	7 021	7.529
10	20 410	23 07	0 595	0 692	144.65	1 6803	7 629	8.232
11	22 451	25 38	0 572	0 673	151 66	1 7483	8 212	8.914
12	24 492	27 08	0 551	0 655	158 48	1 8164	8 774	9 578
13	26.533	29 99	0 531	0 638	165 13	1 8844	9 315	10 224
14	28 574	32 30	0 512	0 622	171.60	1 9524	9 836	10.854
15	30.615	34 61	0.495	0 607	177 92	2.0204	10 336	11.468
16	32 656	36 91	0 479	0 593	184 00	2 0884	10 825	12 068
17	34 697	39 22	0.464	0.579	190.11	2 1565	11.297	12 654
18	36.738	41.53	0 450	0 567	196 01	2 2245	11 753	13.227
19	38 779	43.83	0.436	0.555	201 77	2 2925	12 193	13 788
20	40.820	46.14	0 424	0.544	207.42	2.3605	12 623	14.337
21	42 861	48 45	0 412	0.533	212 95	2 4286	13 044	14.875
22	44 902	50 75	0.401	0 522	218.37	2 4966	13 450	15 403
23	46 943	53.06	0.390	0.512	223.69	2 5646	13.844	15.921
24	48.984	55 37	0 380	0 503	228.91	2 6327	14 230	16 429
25	51 025	57.68	0 370	0.494	234.03	2.7007	14 604	16 927
26	53.066	59 98	0.361	0 485	239 07	2 7687	14 970	17 419
27	55 107	62 29	0 353	0 477	244 02	2 8367	15 327	17 898
28	57.148	64 60	0.344	0 469	248 88	2 9048	15 676	18.371
29	59.189	66 90	0 336	0 461	253 66	2 9728	16 016	18.837
30	61 230	69.21	0 329	0.454	258.37	3 0408	16 348	19.294
31	63.271	71.52	0 322	0.447	263.00	3 1088	16 673	19.745
[illegible]	65.312	73.82	0 315	0.440	267 56	3 1769	16 992	20.190
33	67.353	76 13	0.308	0.434	272 05	3 2449	17 303	20 626
34	69 394	78.44	0.302	0 427	276 48	3 3129	17 606	21.056
35	71.435	80.75	0.296	0.421	280 84	3 3810	17 907	21.480
36	73.476	83 05	0.290	0 415	285 14	3 4490	18 200	21.899
37	75 517	85.36	0 284	0.409	289 38	3 5170	18 487	22.312
38	77.558	87.67	0 279	0 404	293 56	3 5850	18 768	22.718
39	79.599	89 97	0.274	0.399	297.68	3 6531	19 045	23.121
40	81.640	92 28	0 269	0 393	301 75	3.7211	19.316	23.516
41	83.681	94.59	0.264	0 388	305 77	3 7891	19.581	23 908
42	85 722	96 89	0 259	0 383	309 74	3 8571	19 844	24.293
43	87 763	99.20	0 255	0 379	313.66	3 9252	20.101	24.675
44	89 804	101.51	0 250	0.374	317 53	3 9932	20 353	25.052
45	91.845	103.82	0 246	0 370	321 36	4 0612	20 602	25 424
46	93 886	106.12	0 242	0 365	325 13	4 1293	20 846	25 729
47	95 927	108.43	0 238	0 361	328 87	4 1973	21 086	26 155
48	97 968	110 74	0.234	0.357	332 56	4 2653	21 323	26 515
49	100.009	113 04	0.231	0 353	336 21	4 3333	21.555	26 870
50	102.050	115.35	0.227	0 349	339.82	4.4014	21 784	27.221

of design. For low pressures the saving acquired is hardly justified by the multiplication of cylinders and the losses attendant upon the operation of numerous additional parts. Best practice recommends the use of the single-stage compressor up to 70 or 100 lbs., above that amount (preferably 75 lbs.) the use of the compound (two-, three-, or four-stage type compressor).

Of course, as beforesaid, these matters are largely a matter of design, the theory being that the ratios of the cylinders should be such that the final temperatures and M.E.P. in each cylinder should be identical, thereby effecting an equal distribution of the work throughout.

LOSS OF WORK DUE TO HEAT IN COMPRESSING AIR FROM ATMOSPHERIC PRESSURE TO VARIOUS GAGE PRESSURES BY SIMPLE AND COMPOUND COMPRESSION.

(Air in Each Cylinder Initial Temperature, 60° F.)

Gage Pressure.	One Stage.		Two Stage.		Three Stage.		Four Stage.	
	Percentage of Work Lost in Terms of							
	Isothermal Compression.	Adiabatic Compression.	Isothermal Compression.	Adiabatic Compression.	Isothermal Compression.	Adiabatic Compression.	Isothermal Compression.	Adiabatic Compression.
60	29.9	23.0	13.4	11.8	8.6	7.9	4.7	4.5
70	30.6	23.4	14.1	12.4	8.7	8.0	6.1	5.7
80	32.7	24.6	14.7	12.8	9.7	8.9	6.4	6.0
90	34.7	25.8	16.1	13.8	10.5	9.5	7.3	6.8
100	36.7	26.8	16.9	14.5	10.9	9.8	7.8	7.3
125	41.1	29.2	18.5	15.6	11.6	10.4	8.8	8.1
150	44.8	30.9	20.1	16.7	12.3	10.9	9.1	8.4
200	51.2	33.9	22.2	18.1	14.0	12.3	10.5	9.5
300	61.2	37.9	25.7	20.5	16.6	14.2	12.0	10.7
400	68.7	40.7	28.9	22.4	18.2	15.4	13.1	11.5
500	70.6	41.4	31.2	23.8	19.3	16.2	14.1	12.3
600	80.4	44.5	32.8	24.7	20.4	16.9	14.9	13.0
700	85.0	46.0	34.6	25.7	21.3	17.6	16.1	13.8
800	89.5	47.2	35.7	26.3	22.0	18.1	16.2	13.9
900	93.0	48.2	37.1	27.0	22.6	18.5	16.6	14.4
1000	96.1	49.0	37.9	27.5	23.2	18.8	16.9	14.5
1200	102.8	50.7	40.3	28.8	24.8	19.9	17.7	15.0
1400	108.6	52.0	41.5	29.3	25.9	20.5	18.6	15.7
1600	113.4	53.1	43.5	30.3	26.5	20.9	19.2	16.1
1800	117.5	54.0	44.8	31.0	27.3	21.2	19.6	16.4
2000	122.0	55.0	45.8	31.4	27.5	21.5	19.9	16.5

The following are a few of the formulas used by the B. F. Sturtevant Manufacturing Company, large makers of blowers, exhausters, fans, etc., for calculating horse-power requisite for the compression of various quantities of air under various conditions:

(1) $$\text{H.P.}=\frac{VPle\left(\frac{P_1}{P}\right)}{33,000};$$

(2) $$\text{H.P.}=\frac{VP\left(\frac{P_1}{P}\right)^{\frac{1}{3}}-1}{11,000};$$

(3) $$\text{H.P.}=\frac{V(P_1-P)}{33,000};$$

(4) $$\text{H.P.}=\frac{\text{lbs. per sq. in.}\times V}{200},$$

where V = volume of free air in cubic feet per minute;
P = pressure of the atmosphere or suction pressure (absolute) in lbs. per sq. ft.;
P_1 = pressure of compression (absolute) in lbs. per sq. ft.

Of the above, formula (1) is principally used when the H.P. required is for air which is cooled during compression, as in ordinary compressor practice.

Formula (2) when the air is assumed to be compressed so quickly that it does not return to atmospheric temperature. This is the usual case in all blower work.

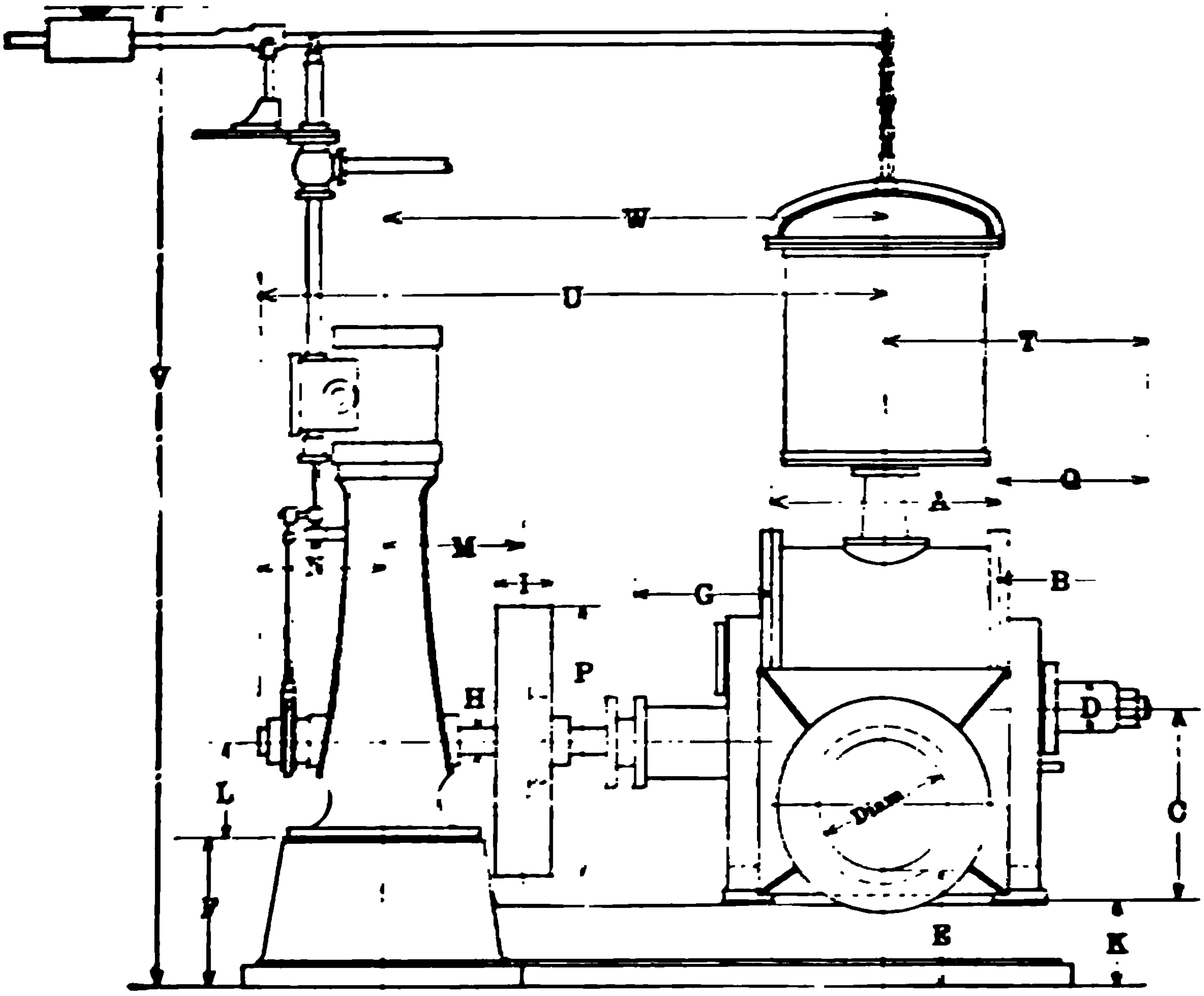
Formula (3) is generally known as the "hydraulic" formula, and in common practice is rarely used above five ounces to half a pound.

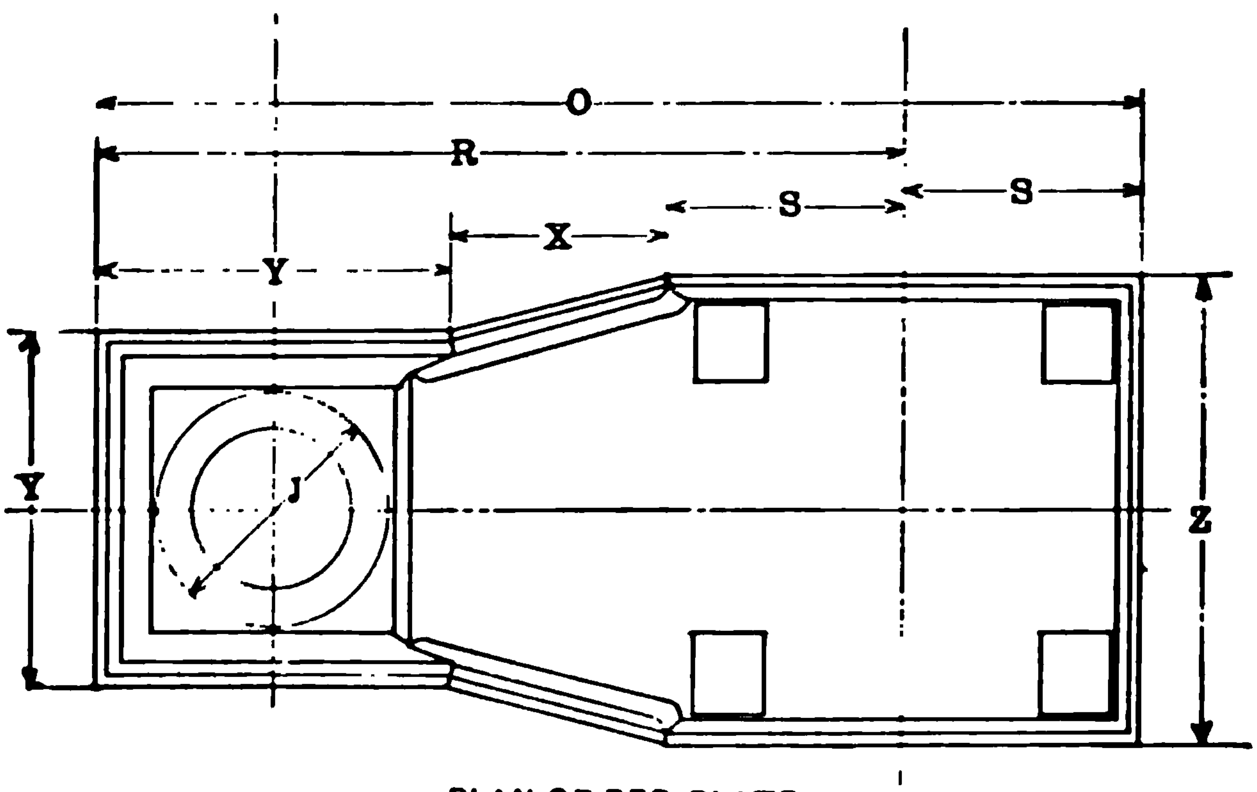
Formula (4) is usually adopted in the case of positive compressors, etc., no allowance being made in this formula for "slip," the calculation being "net."

DIRECT-CONNECTED EXHAUSTERS, Nos 1 TO 5 (Inclusive).

ISBELL-PORTER CO., NEWARK, N. J.

(For data see page 111.)



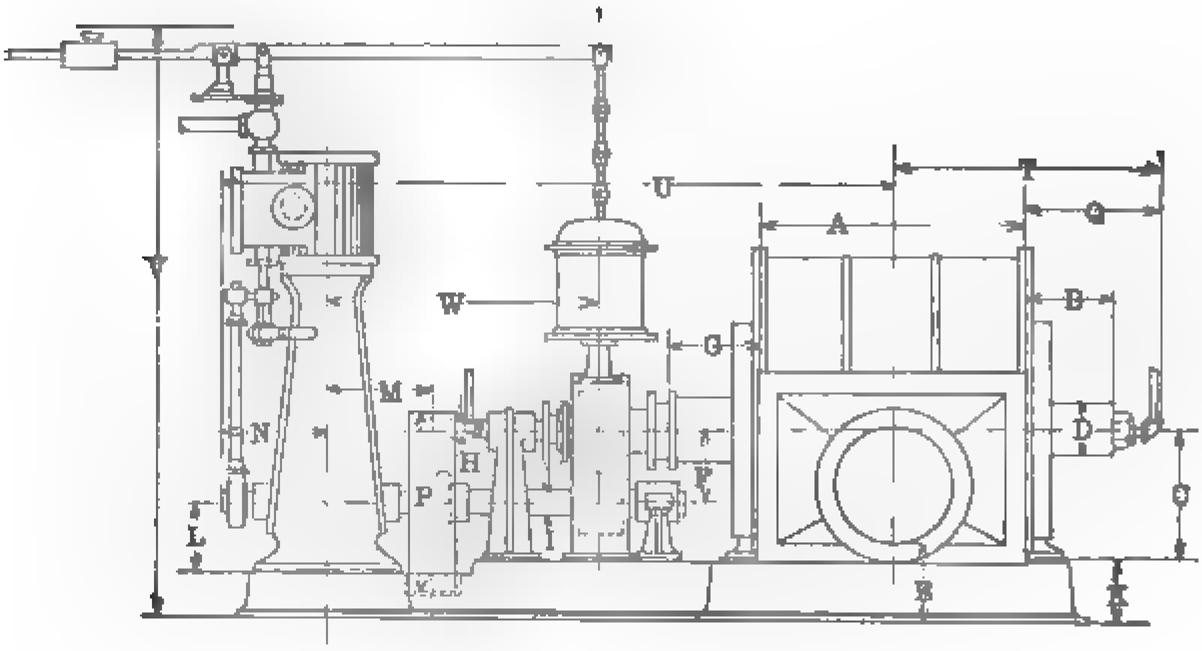


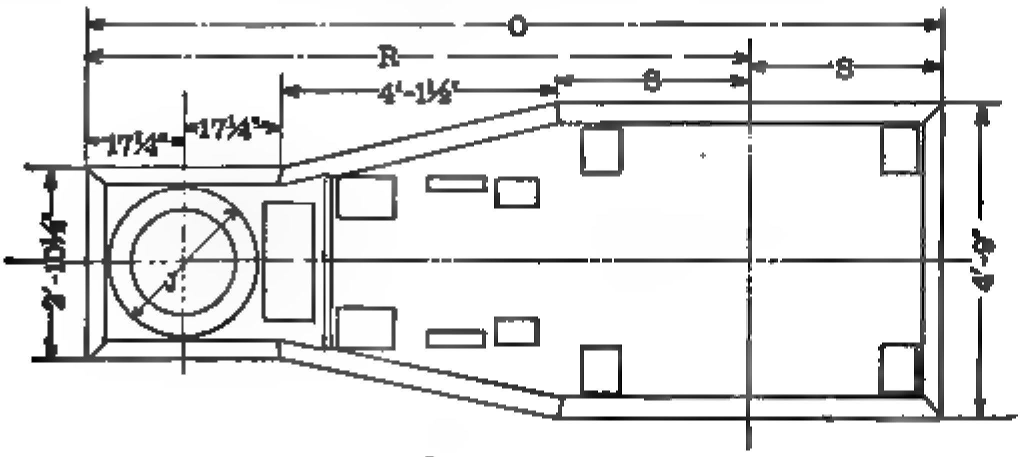
PLAN OF BED-PLATE

GEARED COMBINATION EXHAUSTERS, Nos. 7 TO 12 (Inclusive).

ISBELL-PORTER CO., NEW YORK AND NEWARK, N. J.

(For data see page 111.)



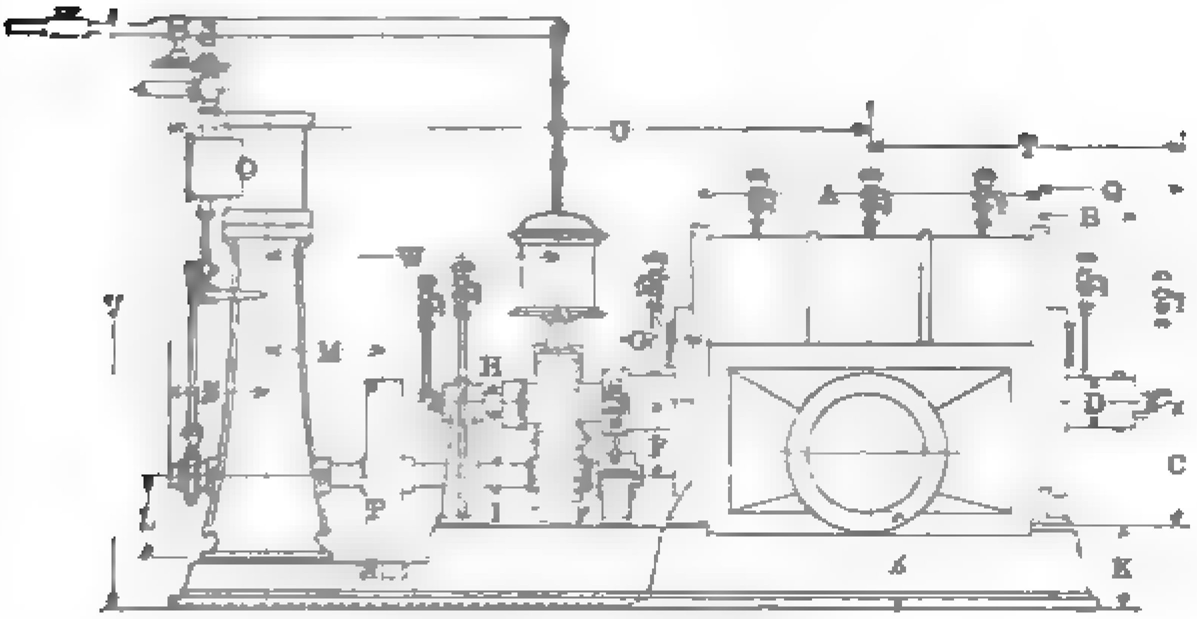


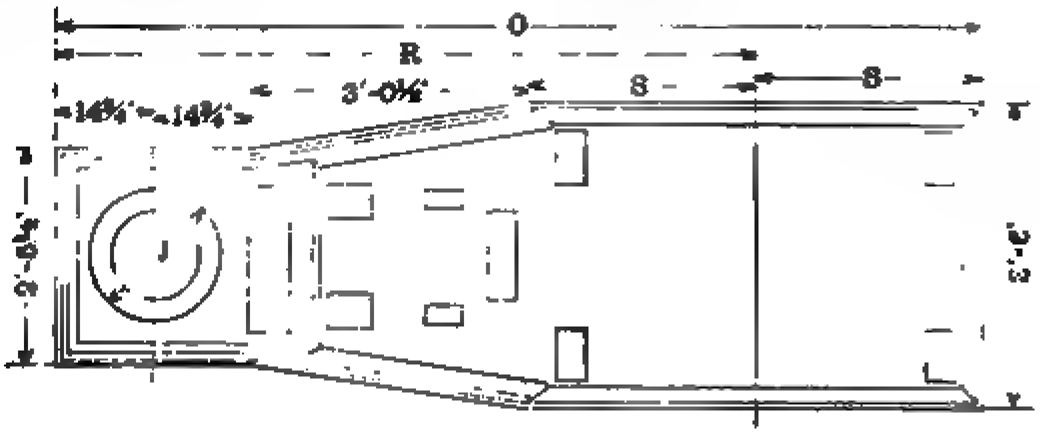
PLAN OF BED-PLATE

COMBINATION EXHAUSTERS, Nos. 13 to 15 (Inclusive).

ISBELL-PORTER CO., NEWARK, N. J.

(For data see page 111.)





PLAN OF BED-PLATE

DIRECT-CONNECTED EXHAUSTERS, Nos. 1 to 8 (Inclusive).

No.	Displacement in Cu Ft per Hr.		Size of Engine	No. of Blades	Length Over Reducers	Diam. of Shell	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
			In		In	In	In	In	In	In	In	In	In	In	In	In	In	In	In	In	In	In	In	In	In	In	In	In	In	In	In	In
1	16050	at 125 R P M	3½ × 5	3	37	22½	11	8 11/16	14 1/16	3	8½	10½	10½	2 1/16	3½	12½	6	7	10½	10	58	22	10½	46½	11½	16	46	72	36	14	21	28
2	21150		3½ × 5	3	37	22½	14	8 11/16	14 1/16	3	8½	10½	10½	2 1/16	3½	12½	6	7	10½	10	61	22	10½	48	13	17½	47½	72	37½	14	21	28
3	26250		4 × 6	3	37	22½	17	8 11/16	14 1/16	3	8½	11½	10½	2 1/16	3½	14	6	6½	10½	10	64	22	10½	49½	14½	19	50	72	39	14	21	28
4	30900		5 × 6	3	37	22½	20	8 11/16	14 1/16	3	8½	11½	10½	2 1/16	3½	14	6	6½	10½	11	67	22	10½	51	16	20½	51½	72	40½	14	21	28
5	38600		5 × 6	3	37	22½	25	8 11/16	14 1/16	3	8½	11½	10½	2 1/16	3½	14	6	6½	10½	11	72	22	10½	53½	19½	23	54	72	43	14	21	28
7	78400	110 R P M	7½ × 8	3	52	34½	20	11½	21½	4½	9½	14½	11 1/16	2½	3½	18	7½	9½	13	14	75	32	13½	58½	16½	23½	59	90	45	15	26½	38½
8	105900		8 × 8	3	52	34½	27	11½	21½	4½	9½	14½	11 1/16	2½	3½	18	7½	9½	13	14	82	32	13½	61½	20½	26½	62½	90	48½	15	26½	38½

GEARED COMBINATION EXHAUSTERS, Nos. 7 to 12 (Inclusive).

No	Displacement per Hour at 110 R P M	Size of Engine	No. of Blades	Gears, 4 D.P.	Length over Reducers	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
		In.		In		In.	In.	In	In	In	In	In	In	In	In	In	In	In	In	In.	In	In	In	In.	In	In.	In	In.
7	78400	7 × 7	3	12 P D. 8 P D	5 ft. 11½ in	20	13 1/16	16½	7	13 1/16	10	11 1/16	2½	2½	18	11½	9½	16	14	102	27	20	84	18	30	83½	72	40
8	105900	7 × 7	3	"		27	13 1/16	16½	7	13 1/16	10	11 1/16	2½	2½	18	11½	9½	16	14	109	27	20	87½	21½	33½	88½	72	40
9	133300	7½ × 8	3	"		34	13 1/16	16½	7	13 1/16	10	11 1/16	2½	2½	18	11½	9½	16	14	116	27	20	91	25	37	90½	72	40
10	156800	7½ × 8	3	"		40	13 1/16	16½	7	13 1/16	10	11 1/16	2½	2½	18	11½	9½	16	14	122	27	20	94	28	40	93½	72	40
11	184300	9 × 9	3	"		47	13 1/16	16½	7	13 1/16	10	11 1/16	2½	3	21½	11½	12	16	17	129	27	20	97½	31½	43½	99½	78	40
12	211700	9 × 9	3	"		54	13 1/16	16½	7	13 1/16	10	11 1/16	2½	3	21½	11½	12	16	17	136	27	20	101	35	47	103½	78	40

COMBINATION EXHAUSTERS, Nos. 13 to 15 (Inclusive).

No	Displacement per Hour at 100 R.P.M.	Size of Engine	No. of Blades.	Gears, 4 D. P.	Length over Reducers.	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
		In		In		In	In.	In	In	In.	In.	In	In	In	In	In	In	In.	In	In.	In.	In	In	In	In.	In.	In.	In.
13	216000	9 × 9	3	17 P D. 8 P D.	7 ft.	36	15½	23½	9	12½	12½	16½	3 1/16	3	22	10½	12	19	17	141	32	24	112½	28½	42	112½	84	49
14	252000	10 × 12	3	16 P.D. 9 P D.		42	15½	23½	9	12½	12½	16½	3 1/16	3	26½	10½	12½	19	17	147	32	24	115½	31½	45	115½	99	49
15	298000	10 × 12	3	"		48	15½	23½	9	12½	12½	16½	3 1/16	4	26½	10½	12½	19	20	153	32	24	118½	34½	48	121½	99	49

CHAPTER IX.

STATION-METERS.

Sizes.—Perhaps one of the most radical improvements in connection with machinery about the works which has presented itself within many years is the introduction of the Hinman drum in station-meters. The advantage of this drum is that it increases largely the capacity of the meter without increasing its cost or bulk.

CAPACITY OF STATION-METERS (OLD TYPE).

Feet.	Cu. Ft. per Hr.
3 × 3	1,250
3.5× 3.5	2,175
4 × 4	3,400
4.5× 4.5	5,000
5 × 5	6,800
5.5× 5.5	8,650
6 × 6	10,800
6.5× 6.5	13,000
7 × 7	16,700
7.5× 7.5	19,300
8 × 8	21,857
8.5× 8.5	25,000
9 × 9	28,650
9.5× 9.5	32,300
10 ×10	36,450
10.5×10.5	41,700
11 ×11	46,875
11.5×11.5	52,000
12 ×12	62,500

The following are the capacities of station-meters of the Hinman drum type, as manufactured by the American Meter Company:

CAPACITY OF STATION-METERS (HINMAN DRUM TYPE).

Feet.	Cu. Ft. per Hr.
6 ×6	22,000
6.5×6.5	25,750
7 ×7	30,000
7.5×7.5	35,000
8 ×8	40,000
9 ×9	52,000

Connections.—A station-meter should be thoroughly cleaned at least twice a year, and should be tested for accuracy as often as cleaned. Fig. 22 shows the proper connections for proving a

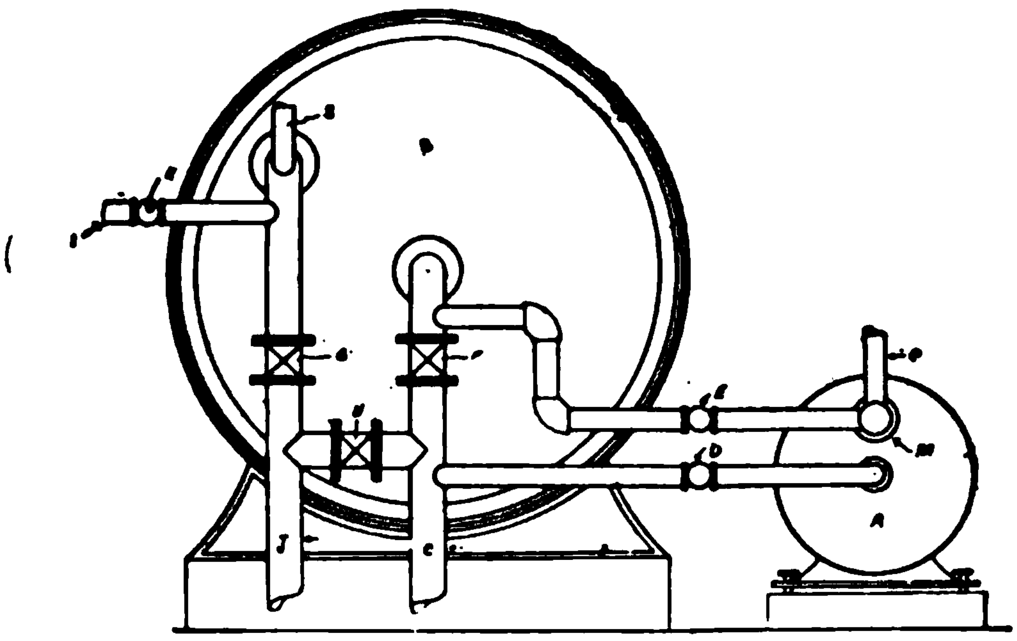


FIG. 22.—Connections for Proving Station-meter.

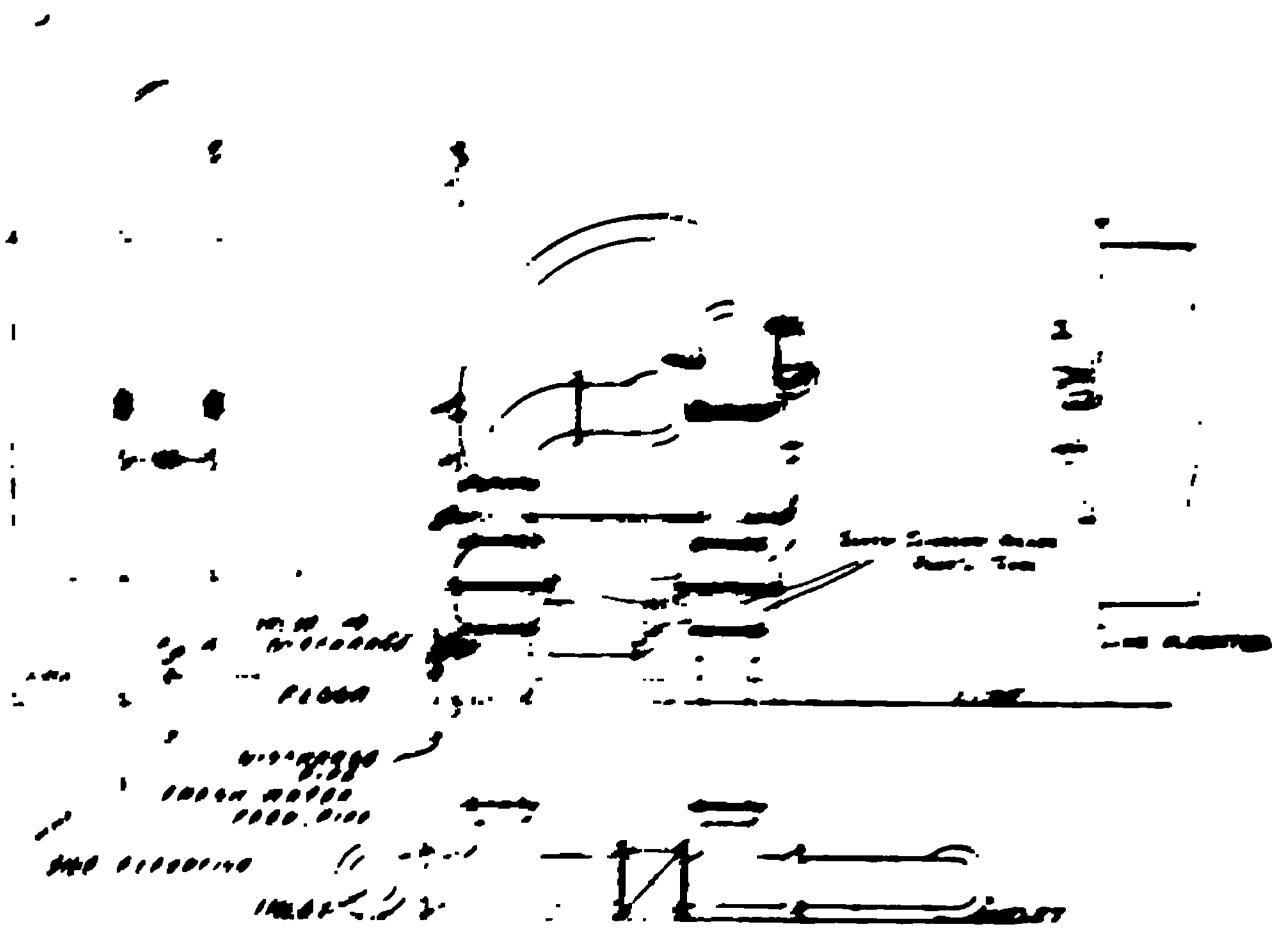
station-meter. The test-meter should be, say, a 60-light meter recently proved on the regular shop meter-prover, and should be connected in as a shunt by-passing the inlet-valve on the station-meter. At least 400 feet of gas should be passed, and the adjustment made by changing the station-meter water-line. The bearings of the meter should at all times be carefully oiled, especially in case of the Hinman type, which revolves much faster than the old-style meter.

While the proving meter is attached, the outlet-valve of the meter should be closed. Should the index of the proving meter move, a leakage will be indicated in the shell and connection of the meter. Should the index of the prover move and that of the station-meter remain stationary, it would indicate a leakage through the drum of the meter. Great care must be taken, however, as to the tightness of the valves or leaks in the connections.

The accompanying sketch (Fig. 23) shows the by-pass connection of the station-meter, which should be invariably used

in connecting in the meter with the mains. By opening the valve on the main out of line and closing the valve on the risers, the meter is by-passed, while by closing the valve on the main out and opening the valves on the risers, the meter is thrown into service.

It will be found of advantage to use valves for this service of the quick-opening type, especially when the sizes of the connections are under 3 in. Such valves are manufactured by the P. H. & F. M. Roots Mfg. Co. The advantage to be obtained by these valves is the extreme rapidity with which they can be worked in throwing in and out the by-pass, and the saving of labor entailed by the old screw-type of valve. Not only the



PIPE CONNECTION FOR STATION METERS.

Fig. [illegible] Rear End and Side View of Station-meter.

meter but the exhauster should also be by-passed after the manner elsewhere described, and there should be a by-pass between the inlet and the outlet of the storage-holder, in addition to which the works connection should be so flexible as to form almost any by-pass combination. For example, there should be a connection from the works direct to the storage-holder, also direct to the town from the outlet of the purifying-boxes, and from the works through the purifying-boxes to the town without the intermediation of any holder. It should also be possible to reverse the direction of flow through almost any section of the works yard-connections.

Volume Correction.—A thermometer should be so attached to every station-meter as to indicate the temperature of gas on the inlet, the volume of which should be corrected to a standard temperature of 60° F. and a pressure of 30 in. of mercury, a table being used for this purpose which is based upon the following formula:

$$V=\frac{17.64(h-a)v}{(460+t)},$$

where V = the corrected volume at 60° and 30 in.;
v = the volume observed at a temperature of $t°$ and h in.;
h = barometer pressure, inches of mercury observed;
a = the tabular tension of aqueous vapor at $t°$.

This formula may be expressed as follows: The corrected volume of a gas saturated with water-vapor at the standard conditions of 60° F. and 30 in. barometric pressure is equal to the observed volume multiplied by 17.64 times the difference between the observed barometric pressure and the tension of water-vapor at the observed temperature and divided by the sum of 460 plus the observed temperature in Fahr. degrees. The tension of water-vapor for the observed temperature must be found from the table giving the tensions for the different temperatures.

The formula is derived in the following manner:

Representing the volume at 60° F. and 30 in. pressure by V, and that of the same mass of gas at any other temperature t and any other pressure h by v, we can form the laws governing the change of volume of gases under the influence of changes in temperature and pressure, and derive the required formula for dry gases. Since the volume varies inversely as the pressure, the product obtained by multiplying the volume at any pressure by that pressure is equal to the product obtained by multiplying the volume of the same mass of gas at any other pressure by the corresponding pressure, and we have

$$30V=hv, \quad \text{or} \quad V=\frac{h}{30}v.$$

Gases expand or contract $\frac{1}{492}$ part of their volume at 32° F. for each change in temperature of 1° F., hence the effect of temperature is shown by the equation $460+t=520$ for 60°, since t is the number of degrees above 0; therefore $460+t$ is equal to 492 at freezing-point or 32° F., while 520 is the number of parts to

which 492 parts at 32° will have expanded when the temperature is raised to 60°. From this we obtain

$$V=\frac{520v}{460+t}.$$

Combining these two equations, we have for dry gases

$$V=\frac{520vh}{30(460+t)};$$

that is, the volume corrected to the standard conditions of 60° F. and a pressure of 30 in. of mercury is equal to the observed volume multiplied by the observed pressure in inches of mercury multiplied by 520 and divided by 30 times the sum of 460 plus the observed temperature.

The correction for moisture depends on the fact that a gas saturated with water-vapor, as will be a gas in contact with water, will, under the same conditions of temperature and pressure, always contain the same quantity of water-vapor. This vapor exerts a certain pressure, which increases with the temperature and is proportional to the amount of vapor present. The pressure so exerted has been determined in inches of mercury for each degree of temperature. To correct for the presence of moisture in a gas saturated with water-vapor it is necessary to deduct the pressure due to the tension of this vapor from the observed barometric pressure, since this barometric pressure is resisted partly by the pressure of the water-vapor and partly by that of the gas, and therefore the pressure exerted on the gas will be really only the difference between the barometric pressure and the pressure due to the tension of the water-vapor. Calling this tension of water-vapor a and taking its value at the temperature of 60° (0.518) to deduct from the standard barometric pressure of 30 in., we have for the formula for reducing the volume of gas saturated with water-vapor observed at any temperature and pressure to that of gas saturated with water-vapor at 60° and 30 in.,

$$V=\frac{(h-a)520v}{(30-0.518)(460+t)}=\frac{(h-a)520v}{29.482(460+t)};$$

or dividing both numerator and denominator of the fraction by 29.482, we get

$$V=\frac{17.64(h-a)v}{460+t}.$$

Standard Unit of Volume.—Some investigation on the part of the writer has revealed the astonishing fact that there is no universally established standard in the United States to which station-meter registrations are corrected; that any number of standards of an arbitrary nature exist, the most common being the average pressure and temperature at which gas is distributed to the consumer's meter, this being for the sake of checking up with the sum total of the said meters, the difference being balanced by the item of "gas unaccounted for," covering shrinkage, leakage, and non-registering of meters.

As, however, the standard pressure throughout the country varies very widely, this will not prove a satisfactory basis for the comparison of manufacturing results, and the writer therefore suggests that there should be two corrections for meter measurements, the one for the benefit of distribution results as above noted, the other the universal standard for gas comparison measurements of 60 deg. F. and 29.7 or, usually, 30 in. barometric pressure.

It is scarcely necessary to lay further emphasis upon the advantage of having these two standards of comparison universally adopted, for only by some such means can any uniformity of results or exactness of data be obtained. The latter or atmospheric standard is now universally in vogue in light measurements and standard photometry.

The writer further suggests that the *temperature* in both equations for measurement should be taken from the gas itself, and not the station atmosphere, as, in small or large works where the storage capacity is limited, the gas is frequently forced through the meter not only under extraordinary pressure but at a high degree of temperature.

It will now be seen that under such conditions there can be no uniform comparison of measurements, as they will vary at different seasons of the year, by reason of both temperature and demand upon manufacture, due, for example, to such details as the ratio between condensing capacity and amount of gas manufactured, this being inverse, as well as the actual atmospheric temperature.

In order to avoid any possible difference in the conditions, or bases of comparison of manufacturing results, measurement, or data, the writer strongly urges that all such figures be generally understood, without further particularization, as being based upon the universal standard of 30 in. barometric pressure and 60 deg. F.

Roughly speaking, all gases expand nearly 1 per cent. for every 5 degrees rise in temperature. The volume of the gas varies di-

rectly as the absolute temperature, and inversely as the absolute pressure.

One of the most convenient ways for correcting the station-meter measurement of gas for pressure, where the pressure is exerted by the weight of the holder (which is approximately constant), is to set the station-meter a sufficient amount fast to compensate for this difference. This method, however, has its drawbacks; one, for example, being where it is necessary to reduce the reading to average pressure and temperature of distribution for the purpose of balancing up and checking consumers' meters, gas unaccounted for, etc. It is perhaps better to convert the holder pressure, usually in inches of water, to inches of mercury, by the use of coefficient 0.0735 inch and correcting by use of the table elsewhere given.

Operation Hints.—There should be a pressure-gage on the inlet and one on the outlet of the station-meter, the difference in their registration forming the differential pressure. This should in no instance exceed 1.5 in., a greater resistance indicating that the meter is forced. The valves on the pressure-gages, as well as on the water-line, should be opened and closed occasionally, and if much dirt collects on the glass of the gages, the valves should remain open only just wide enough to admit the pressure, thus excluding a certain amount of dirt and lessening the rapidity of circulation. It will also prevent excessive fluctuation of the meniscus in the gage-glass. The stream of water which is fed to the meter should be just sufficient to keep a correct water-level, the discharge-pipe on the overflow just dripping. The overflow-gage on the rear head of the meter is intended to show that the water in the drum is at its proper level. Care should be taken that its opening and connections should at all times be free of obstruction, as upon this depends the accuracy of the meter. The top of the overflow-gage should be connected to the inlet-pipe of the meter only, and the bottom should be trapped close to the gage. This trap should be allowed to discharge through a funnel and should not in any way be connected to any waste-pipe or sewer, as such an arrangement is liable to siphon the water from the meter.

The index of the meter should be kept clean and occasionally oiled with some high-grade clock-oil. The train of gears may be occasionally greased with a little tallow or graphite, as should the spindle running through the front head of the meter, around which the packing should be changed whenever it becomes hard. This packing may consist of leather washers, yarn, tallow, or graphite.

At times a grinding or pounding noise may be heard inside

the meter, especially during maximum load. This may occur from a break or buckle in the plates of the drum, the drum-centers being loose on the shaft, or from lost motion on the part of the shaft in a worn journal, or from the grinding of the drum due to thrust on the part of the shaft.

As before stated, when the station-meter is tested the water-line should be carefully established, and a bench-mark placed upon the meter-case. This being done, a daily inspection should approve the conformity of the meniscus in the water-gage to such mark. This mark should be invariably located after the final establishment of the meter, instead of relying upon the shop-mark usually placed by the manufacturer.

One method of correcting meter measurement for holder pressure is to connect a U gage on the inlet of the meter and fill it with mercury. The reading of this gage may be added to that of the barometer and the sum of their readings compared with a table for correction.

ROTARY METERS.

The Rotary Meter Co. of New York City have recently placed upon the market a form of station-meter which, although invented by Mr. Thomas Thorp, the pioneer of the "slot meter," some years since, and well known for some time in English works, is new to the American market.

The principle of the meter, which is illustrated by Fig. 24, is that of the anemometer, and it is adapted at high or low pressure to air, natural or any and all forms of manufactured gas.

The safe working pressure of these meters is up to 150 lbs., and they are arranged in the case of high pressure to compensate, the reading being mechanically corrected to indicate the flow of gas at atmospheric pressure.

The minimum measuring capacity of these meters is one-tenth that of the maximum capacity, the meter registering accurately only between these limits.

The chief claims for this type of meter are its small size (one-tenth the bulk of the old type station-meter), low cost (one-half that of the old type), and extreme durability. The cheapness and small size of these meters bring them within the range of works economy, to meter the output of various sections of apparatus, and thus to analyze the conditions of output in a manner impossible under the old arrangement.

In this connection the same company are getting out a small consumer's meter (see Fig. 25), which is known in England as a "rebate meter" by reason of its use for determining the amount

of gas used by the consumer for other than illuminating purposes, upon which special concessions were made. It is likely that the

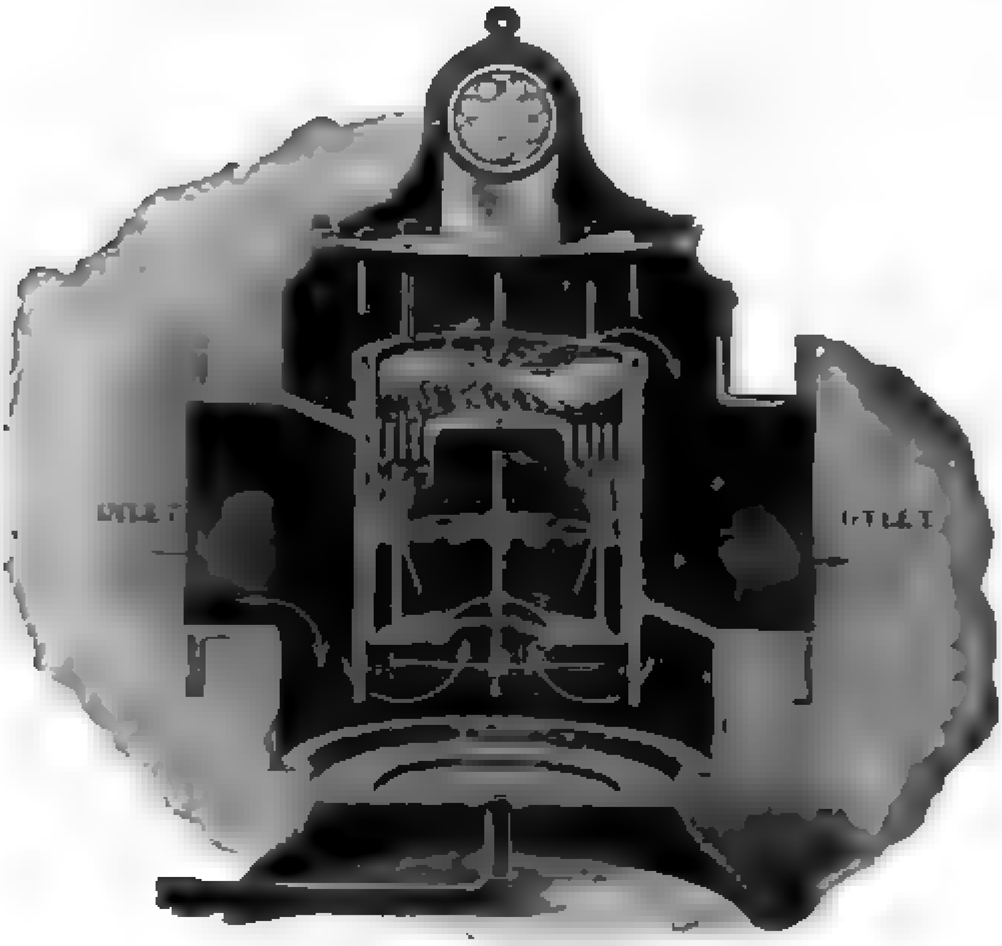


FIG. 24.—Section of Rotary Station-meter.

use of such meters, connected directly upon the gas-burning appliance and continually beneath the eye of the consumer, will in the future materially increase economy in operation.

ROTARY STATION-METERS.

No.	Cu. Ft. per Hr., Minimum Capacity.	Cu. Ft. per Hr., Maximum Capacity	Dimensions in Inches.						Weight, Pounds.
			A	B	C	D	E	F	
1	150	1,500	13¼	9	4¾	7⅛	3	5½	62
2	350	3,500	16	13	9¾	9¾	4	10	166
3	500	5,000	24	21	12¾	14¾	6	12	380
4	750	7,500	28	21	16	16½	8	15½	560
5	1,000	10,000	32	24	18	18	10	18	901
6	1,500	15,000	36½	28	20½	21	12	20½	968
7	3,000	30,000	49	37	25	26	15	23	1,918
8	4,500	45,000	60	50	29	32	20	29	2,884
9	6,000	60,000	72	54	30	40½	24	33	4,533
10	10,000	100,000	96	72	36	48½	30	39	7,985

FIG. 25.—Dial of Rotary Meter.

CHAPTER X.

HOLDERS.

All holders should be periodically inspected for leaks, both gas and water. The crown sheets of holders are so constructed with calking edges as to be, in most instances, readily repaired. For leaks in the holder-tank a daily scattering on the surface of the water of a mixture of half Portland cement and half very fine coke ashes, say generator screenings, will be found to take up the majority of small leaks.

The carriages of all holders should be frequently inspected, and immediately adjacent to them should be outlets and connections for steam-hose, having steam connection with the works. This steam should also be connected to the drips.

Pressure.—In case it is necessary to increase the gas pressure upon the town, it is frequently necessary to weight the holder. The writer has found for this purpose old railroad T rails (60-ft. lengths) or I beams and channel-bars to be excellent, inasmuch as they give an even distribution of weight over a considerable surface and are easily handled, besides which, using them as units, an equal balance of weight can be effected by placing them radially to the center of the holder.

A table of the weights of gas-holders in pounds for every one-tenth of an inch maximum pressure required, from 20 to 200 ft. in diameter, is given on page 123.

Holder Pressure.—To obtain the pressure which a gas-holder will throw, take the weight of holder in pounds, divide by the diameter squared, multiply by 0.4091, which will equal the pressure thrown in tenths of an inch, or

$$P=\frac{W}{5.21A}.$$

The relief-holder acts largely as a governor in producing an even flow of gas from the cupolas through the purifying apparatus and, therefore, is an indispensable adjunct to water-gas equipment. As the flow of gas is intermittent from the machines,

the relief-holder serves as an equalizer, enabling the gas to flow in a continuous stream from its outlet, varying but slightly from one period to another.

WEIGHTING OF GAS-HOLDERS.

Diameter of Gas-holder in Feet.	Weights in Lbs. for each 0.1 of an Inch Gas Pressure.	Diameter of Gas-holder in Feet.	Weights in Lbs. for each 0.1 of an Inch Gas Pressure.	Diameter of Gas-holder in Feet.	Weights in Lbs. for each 0.1 of an Inch Gas Pressure.
20	164	64	1,676	108	4,772
21	181	65	1,729	109	4,861
22	198	66	1,782	110	4,950
23	217	67	1,837	111	5,041
24	236	68	1,892	112	5,132
25	256	69	1,948	113	5,224
26	277	70	2,005	114	5,317
27	298	71	2,062	115	5,410
28	321	72	2,121	116	5,505
29	344	73	2,180	117	5,630
30	368	74	2,240	118	5,696
31	393	75	2,301	119	5,793
32	419	76	2,363	120	5,891
33	446	77	2,426	121	5,990
34	473	78	2,489	122	6,089
35	501	79	2,553	123	6,189
36	530	80	2,618	124	6,290
37	560	81	2,684	125	6,392
38	591	82	2,751	126	6,495
39	622	83	2,818	127	6,598
40	655	84	2,887	128	6,703
41	688	85	2,956	129	6,808
42	722	86	3,026	130	6,914
43	757	87	3,097	131	7,021
44	792	88	3,168	132	7,128
45	828	89	3,241	133	7,237
46	866	90	3,314	134	7,346
47	904	91	3,388	135	7,456
48	943	92	3,463	136	7,567
49	982	93	3,538	137	7,678
50	1,023	94	3,615	138	7,791
51	1,064	95	3,692	139	7,904
52	1,106	96	3,770	140	8,018
53	1,149	97	3,849	141	8,133
54	1,193	98	3,929	142	8,249
55	1,239	99	4,010	143	8,366
56	1,283	100	4,091	144	8,483
57	1,329	101	4,173	145	8,601
58	1,376	102	4,256	146	8,720
59	1,424	103	4,340	147	8,840
60	1,473	104	4,425	148	8,961
61	1,522	105	4,510	149	9,083
62	1,573	106	4,597	150	9,205
63	1,624	107	4,684	200	16,364

Freezing of Tanks.—The freezing up of holders is a problem requiring a good deal of attention during the colder months of the year, and all holders should be fitted at frequent points with connections for steam-hose, and a main steam-line should be connected with the works and these outlets for instant service. A good form of steam-jet is proposed by the gas educational trustees of the American Gaslight Association, a cut of which, slightly modified, is herewith inserted (Fig. 26). The only fittings needed are a 1-in. T and a $\frac{3}{4}$-in.×1-in. (or better a $\frac{1}{2}$-in.×1-in.) bushing. Into one of the openings screws a $\frac{3}{4}$-in. steam-pipe threaded on the inside, into which has been screwed a plug, in the center

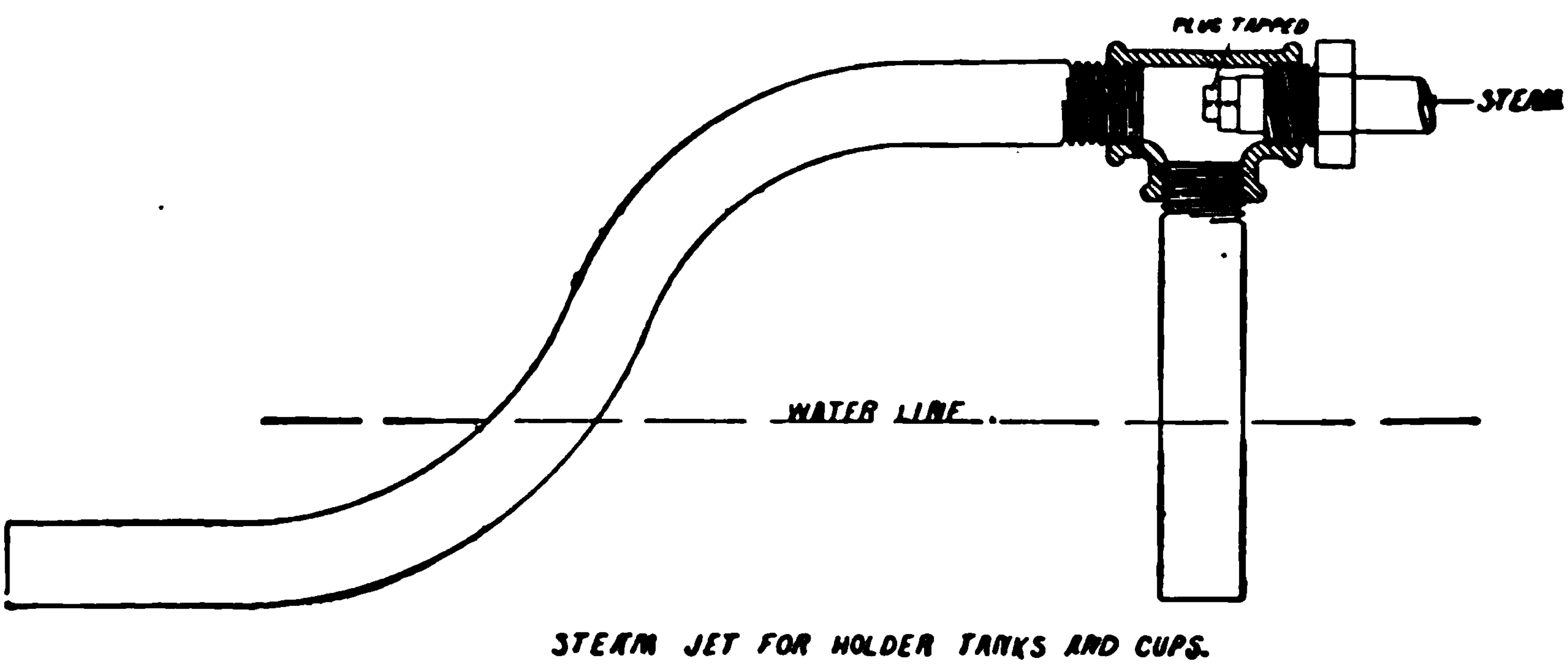


FIG. 26.—Position of Circulation Jet for Water in Tanks.

of which has been drilled a hole; this plug should project a little past the center of the T. A piece of 1-in. pipe, about 18 in. long and offset about 6 in., is screwed into the other outlet of the T. Another piece of 1-in. pipe, from 6 to 8 in. long, is screwed into the side outlet of the T. When placed in position the T is set just above the water-line of the holder-tank or cup, with its run horizontal, and the side outlet of the T, into which is screwed the 6- or 8-in. section, directed downward into the water and extending 4 to 5 in. below the water-line, as is also the offset end of the other outlet. When the steam is turned on, a jet issuing from the drilled orifice creates a vacuum in the side-outlet nipple, and the water rises in this nipple and is blown along with the steam through the offset piece; thus this jet not only heats the water but also induces a rapid circulation around the cup of the tank, and is, therefore, more effective than a jet which merely blows steam into the water, for water will not freeze as quickly when in motion as when comparatively at rest.

Cleaning Tanks.—It is occasionally necessary to remove mud, muck, or other accumulations from the bottom of a holder, which can be most readily accomplished by the use of a basket-shovel, or grab-bucket, swung on the end of a 1-in. pipe. After the heavier substance has been removed, the remaining mud and tar can be stirred up and the solution pumped out and replaced with clean water. Such stoppages, when they occur in the inlet- and outlet-pipes, can be removed in a like manner. Big tampers of wood nearly fitting the diameter of the pipe can be used to advantage to churn and break away stoppages adhering to the sides, after which the contents may be flushed.

In case of a leak occurring in a holder-tank, the following suggestions have been made by various gas-engineers: Insert in the water of the tank, at a point as near as possible to the aperture, sawdust, bran, barley sprouts, or, better still, horse-manure. The better way, where cracks are vertical, is to cement them while the tank is full of water. Sheets of canvas saturated with coal-tar can also be let down into the tank and will be held against the aperture by the pressure of the water.

Patches.—It sometimes occurs that it is necessary to put a patch upon a gas-holder over a ragged hole in the holder-sheet too thin to tap in a thread. A cut of such work (Fig. 27) will be found on the next page. It consists of a sheet of iron or steel of such size and shape as to extend with a good wide lap over the orifice to be covered. Oblong holes, say $1 \times \frac{5}{16}$ in., with the long axis at right angles to the edge of the plate, about 2 in. apart and $\frac{3}{4}$ in. space between the outer edge of the hole and edge of the plate, are to be made around the perimeter of the patch. The heads of a sufficient number of $\frac{1}{4}$-in. bolts should be flattened until they are only $\frac{1}{4}$ in. wide. The patch should then be held against the sheet over the hole, until bolt-holes are made in the sheet to correspond to those in the patch, the first two made being at diagonally opposite corners. The patch can then be temporarily applied by keying it on with the flattened head bolts already prepared, one bolt being passed through each corner and the nut being screwed down, a washer having first been put on. Putty or white lead should be smeared around the edges of the patch to stop the escape of gas while the remaining work is proceeding. The holes may be made by means of a breast-drill and a rat-tail file. When the holes are all completed, the patch should be removed, the flow of gas being temporarily stopped by pressing over the orifice another sheet of iron, wet gunny-sacks, etc. A putty composed of equal parts of red lead and litharge mixed in glycerine should be coated over the patch, when the patch should be reapplied and permanently bolted.

The hole around each bolt, before the washer is finally applied, should be filled in with this putty, and a strand of lamp-wicking smeared with the preparation should be tied around the bolt prior to the application of the washer, and finally the nut. These washers should be $1\frac{1}{4}$ to $1\frac{1}{2}$ in. in diameter.

If the hole is a large one and the pressure considerable, means must be taken to apply the patch temporarily while the holes,

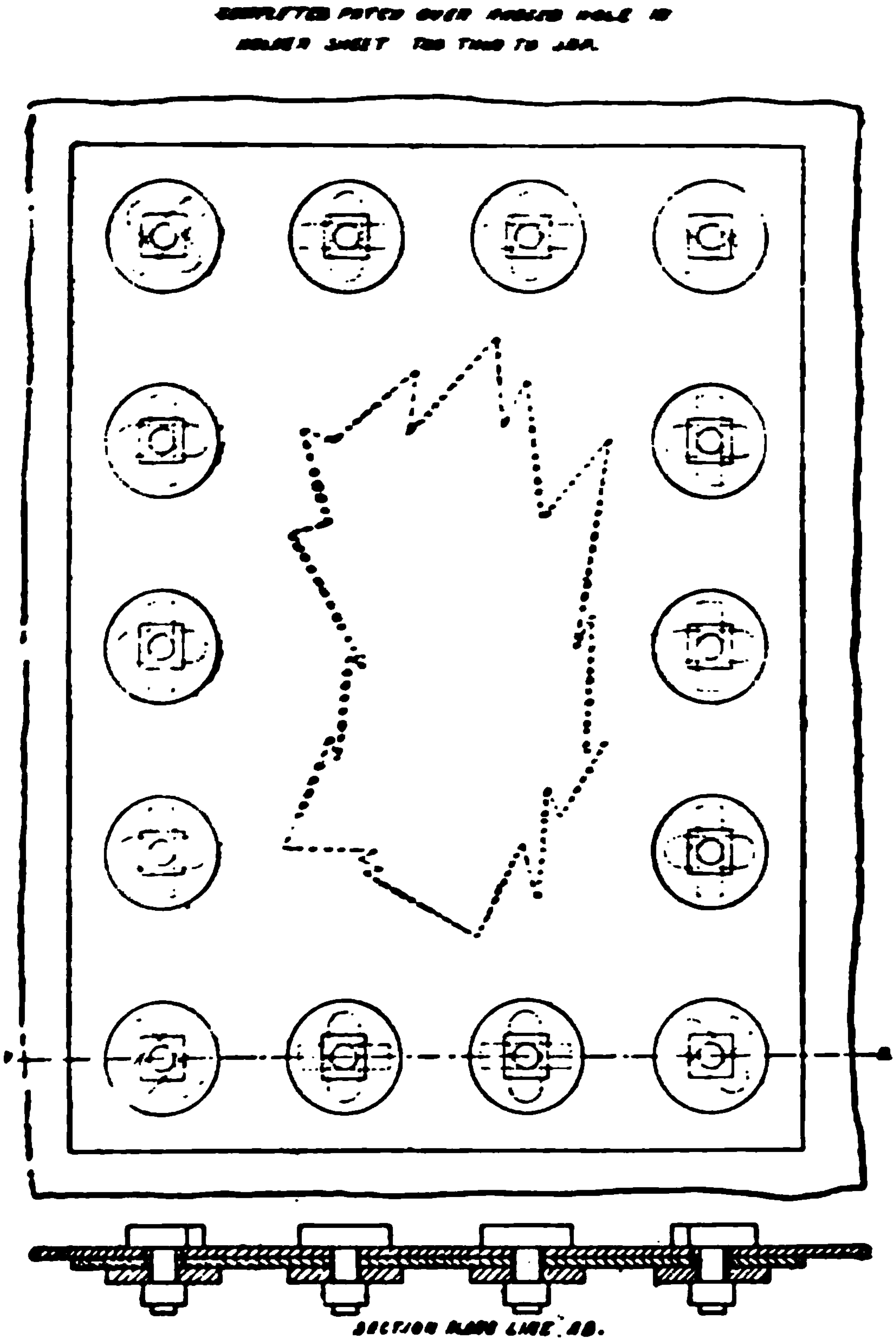


FIG. 27.—Patching Rent in Holder-sheet.

etc., are being drilled. In the case of a crown-sheet this can be done by simply laying the patch over the hole and weighting it down; but in the case of a side hole, eye-bolts may be attached to the side of the sheet, and the patch clamped on by means of a chain or rope running around the holder, and, by the use of block

and tackle, tightly pulled up and cleated. The eye-bolts may be sawed off after the patch is permanently attached.

Capacity.—The ratio of holder capacity to daily consumption in small works generally equals 1 to 1. In larger works this ratio is generally decreased, some of the larger plants of the country having only half the storage capacity of their daily output. It is less necessary to have this ratio equal in the case of water-gas than in that of coal-gas. In both instances it should depend considerably upon manufacturing capacity. In no instance, however, in the opinion of the writer, should the minimum storage capacity exceed 85 per cent. of the maximum daily demand.

The wash-water from the condensers is sometimes successfully pumped to and from the relief-holder, thereby reducing the temperature of the water and economizing the quantity used.

Salt should never be used in holder-cups for the prevention of freezing, by reason of its injurious effect upon the metal of the holder.

TO OBTAIN WEIGHT OF ANY HOLDER.

Diameter^2 $\times$ pressure in $\frac{1}{10}$th inch $\times 0.4091 =$ weight of holder in pounds.

TO OBTAIN PRESSURE WHICH A HOLDER WILL THROW.

$$\frac{\text{Weight of holder in lbs.}}{\text{Diameter}^2 \times 0.4091} = \text{pressure in } \tfrac{1}{10}\text{th inch.}$$

WEIGHT AND PRESSURE OF HOLDERS.

$$P = \frac{W}{\text{area} \times 5.21}; \qquad W = P \times \text{area} \times 5.21.$$

CALCULATIONS FOR HOLDER PRESSURE.

Single-Lift Holders.

Let P be the pressure of water column in inches;
W the weight of holder in pounds;
D " diameter of holder in feet.

Then
$$P = \frac{0.245 \times W}{D^2}. \quad \dots\dots\dots \quad (1)$$

If we consider that the pressure changes with the different height of shell above the water-line, the following formula will have to be observed:

$$P = \frac{0.245 \times W}{D^2} - \left[\frac{0.0315 \times S(H-h)}{HD^2} + 0.00928h\right], \quad . \quad (2)$$

in which S represents weight of shell in pounds;
H " the entire height of shell;
h " the height of shell above water.

Two-Lift Holders.

If D = the diameter of inner lift;
W = weight of the inner lift in pounds;
W_1 = " " " outer " " "
W_2 = " " " water in the cup in pounds;
S = " " shell of inner lift in pounds;
H = height of inner and outer lifts, minus cup, in feet;
h = " above water.

Then, if only the upper part is working,

$$P=\frac{0.245\times W}{D^2}-\left(\frac{0.0315S(\frac{1}{2}H-h)}{D^2\frac{1}{2}H}+0.00928h\right) \quad . \quad . \quad (3)$$

should be used. If both are working, the following formula is applicable:

$$P=\frac{0.245(W+W_1+W_2)}{D^2}\cdot\left(\frac{0.0315(S+W_1)(H-h)}{D^2H}+0.00928h\right). \quad (4)$$

In the last or fourth formula we included the bottom ring of the outer section, which is not correct, but the difference is so small that it would not alter the result.

The pressures obtained by following the given formulas would be maximum. The minimum pressures, however, can be readily calculated by deducting from the weight of holder, in pounds, the tendency of the gas to rise, in pounds. For example, if C would represent the capacity of the holder above the water-line, in cubic feet, S the specifie weight of gas, and A the weight of one cubic foot of air, we obtain, by using formula (1),

$$P=\frac{0.245\times W-C\times S\times A}{D^2}.$$

WEIGHT OF SNOW (TRAUTWINE).

Fresh-fallen snow per cubic foot, 5 to 12 lbs.

Moistened and compact by rain, 15 to 50 lbs.

For the reduction of wind pressure on a circular surface to an equivalent plane area (such as an arched roof or a gas-holder)

Prof. Rankine	gives	0.5
M. Arson	"	0.46
R. J. Hutton	"	0.67
W. H. Y. Webber	"	0.5
Molesworth	"	0.75
G. Livesey	"	0.57
Prof. Adams	"	0.7854

Walmisley gives................ 0.56
V. Wyatt " .... 1.0 (October, 1887)
Bancroft " 0.5
Cripps " 0.3
Sir B. Baker " 0.41
Newbigging " .... 0.5 area of section
Trautwine " .... 0.5 " " "
Prof. Kernot (of Melbourne University) gives................ 0.5 " " "

FORCE OF THE WIND.
(O'CONNOR.)

Velocity.		Force.	
Miles per Hour.	Feet per Second.	Lbs. per Square Foot.	
1	1.47	.005	Hardly perceptible.
2	2.93	.012	
3	4.40	.044	Just perceptible.
4	5.87	.048	
5	7.33	.123	Gentle, pleasant breeze.
	10.0	.229	
10	14.67	.300	Pleasant, brisk gale.
	20.0	.915	
15	22.0	1.107	
20	29.34	1.968	
	30.0	2.059	
25	36.67	3.075	Very brisk gale.
	40.0	3.660	
30	44.01	4.429	
	50.0	5.718	
35	51.34	6.027	High winds.
40	58.68	7.873	
	60.0	8.234	Hard gale.
	70.0	11.207	
50	73.35	12.300	Very high winds.
	80.0	14.638	
60	88.12	17.715	A storm.
	90.0	18.526	
	100.0	22.872	A great storm.
	110.0	27.675	
80	117.36	31.490	A hurricane.
	120.0	32.926	
	130.0	38.654	
90	132.02	39.852	
	140.0	44.830	
100	146.7	49.200	
	150.0	51.462	
120	176.04	70.860	

Paint.—As a holder, purifying-box, or gas-machine paint, the writer, after a number of years of experiment, has obtained the best results from the Eclipse graphite paint called "gas-house red," as manufactured by the Acme White Lead & Color Works. This paint is manufactured of pure graphite. It possesses a heavy body and attractive appearance, and will stand almost any degree of temperature without cracking or scaling.

Placing in commission holders, purifying-boxes, mains, or other apparatus. These should be purged by expelling the air which they contain through a double water-sealed siphon, at the outlet of which may be a test light which may be operated with immunity from explosion.

Old paint and rust should first be removed from a holder before re-painting, by the use of wire brushes or scrapers, or, better still, by a sand-blast.

Locating a site for a holder should be a matter of the most careful consideration. Other conditions being satisfactory, a first test should consist of making a boring in the ground with an earth auger to a depth of 20 ft. and recording the character of the soil as the borings are brought to the surface. The second test should be the weighting of a square foot of the ground (at a number of places to obtain a general average) with a load of from 2500 to 3000 lbs., being balanced upon a short piece of 12×12 timber (standing on end). Before the load has been applied, take the elevation of the top of the timber with regard to a bench-mark, then immediately after the application of the weight, continuing to note the amount of settlement, until same apparently ceases. Then by subtracting the last elevation from the first, the total settlement can be ascertained, together with the sustaining quality of the ground, from which data the character of the foundation necessary may be intelligently determined.

Piling should be avoided wherever possible, and only resorted to where piles can conveniently reach to bed-rock, and where marshy soil or quicksand is encountered it is invariably ultimately cheaper to procure another or different site. The Stacey Manufacturing Co. cite a recent instance of a holder of about 1,500,000 cu. ft. capacity, erected upon soft ground at a cost for piling of 75 cents per square foot, over the whole area of same. These piles were capped by two feet of concrete, composed of good Portland cement, clean coarse sand and broken stone; but the foundations failed immediately upon the filling of the holder tank with water.

CHAPTER XI.

DETAILS OF WORKS OPERATION.

ALL valves about works, mains, or pipe systems should be distinctly marked "open" or "shut," with arrow marking direction of rotation; generally some one valve, right-hand or left-hand, should be universally adopted to prevent confusion, and when so adopted there should be *no exception* to this rule.

There can be no doubt that the standard of gas service for the future, maintained either by municipal legislation or by the gas-engineer, will be based upon the calorific value of the gas. This may be ascertained in two ways: first, by analysis of the gas and by the addition of the heat values of its constituent factors; secondly, by the direct use of calorimeters. There are several types of this instrument, of which the Junker is perhaps in most general use. Another in common use in England is that named Simmance and Abady. A recording instrument has recently been patented by F. N. Speller. The subject of the measurement of temperatures has been best treated by Le Chatelier and Boudouard of Paris, of whose work there is an excellent English translation.

Where the Jones jet photometer is used to check the candle power at the works it should be placed in such a position that the temperature will be as nearly as possible constant. As the readings depend principally upon the specific gravity of the gas, they may vary by reason of temperature. It should be periodically standardized against a bar photometer and its value noted. This should occur at no greater interval than once a week where it is used to indicate actual candle power. Its principal use is a check upon works operation.

The reading of water-gages may be done more accurately and the meniscus more clearly defined by dropping into the water a small portion of cochineal, mixed in hot water, which is first filtered and the color fixed by the addition of a few drops of nitric acid.

The following readings should be taken daily in every gas-works:

1. Temperature of air (average atmospheric).
2. Average barometric pressure.
3. Photometer and calorimeter reading of the gas.
4. Temperature of gas at each stage of manufacture, condensation, scrubbing, purification, etc.
5. Hourly temperature of gas passing through station-meter.
6. Pressure of gas throughout every point in the works and on the town, the latter being recorded mechanically.
7. Purifiers changed.
8. Records of test for sulphur at inlet and outlet of purifiers.
9. Test-cards from sight-cocks on superheater, showing traces of either tar or lampblack, or probably fixed oil.
10. Gas on hand in holders.
11. Oil on hand in tanks.
12. Tar on hand in tanks.
13. Coke or coal used.
14. Oil used.
15. Percentage of ash or screenings.
16. Station-meter indexed.
17. Air-meter indexed.
18. Average pressure of gas through station-meter (mechanically registered).
19. Differential pressure or resistance of station-meter at maximum load.
20. Average gallons oil and pounds of generator fuel used per 1000 cu. ft. manufactured.

The Green fuel-economizer is a special device for heating feed-water, the apparatus consisting of a coil of pipes with an automatic scurfing device, through which the waste gases of the superheater pass. Experiments show that these gases enter the economizer at a temperature of about 1500 deg. F., and leave it at between 400 and 700 deg. Through the heat thus absorbed the feed-water is enabled to enter the boiler at 350 deg., effecting a considerable saving of boiler fuel. The only objection to this apparatus is the rather considerable cost of installation in the case of small works, the arrangement being particularly fortunate where gas and electric works are combined and the steam production amounts to a large portion of the total manufacturing cost. At the present time the Green Economizer Company are at work on another type of generator, with which they will preheat the blast air, permitting it to enter the retorts at a temperature of about 400 deg., and effecting not only a saving from 6 to 8 per cent. in generator fuel, but a very considerable saving in the de-

terioration caused by the chill to the checker brick of the other two retorts.

Where large valves are frequently used and are important in their nature they should be surrounded by manholes properly covered to facilitate repairs and render them easy of access.

Flow of Water.—Great loss is sustained about works, offices, etc., by the leaking of various water fixtures, due to a failure on the part of valves to properly seat, and the water escaping therefrom, often without possibility of detection, through drains and sewers. The following paragraph and table are taken from a paper written by W. L. Calkins, hydraulic engineer:

"Few people have even an approximate idea of the quantity of water which may be wasted through small openings, and for this reason I give the following table, which gives the number of gallons of water discharged through various small openings in 24 hours, under a pressure of 60 lbs. per square inch:

Diam. of Orifice, Inch.	Gallons.
$\frac{1}{64}$	61
$\frac{1}{32}$	230
$\frac{1}{16}$	907
$\frac{1}{8}$	3,649
$\frac{1}{4}$	14,616
$\frac{3}{8}$	32,558"

PART II.

GAS DISTRIBUTION.

CHAPTER XII.

NAPHTHALENE.

Naphthalene is a hydrocarbon formed in comparatively small quantity (about 13.15 lbs. per ton of ordinary English coal distilled in coal-gas retorts, according to R. W. Irwin) during the distillation at high temperatures of carbonaceous substances such as coal and petroleum. It has been claimed that naphthalene can be formed in the gas after it leaves the retorts and during distribution, but this view is generally held to be incorrect, and from the present knowledge of the subject it seems practically certain that all of the naphthalene found either in coal-gas or coal-tar is produced during the distillation of the coal in the retorts. The molecule of naphthalene is composed of 10 atoms of carbon and 8 atoms of hydrogen, its chemical symbol being $C_{10}H_8$.

Properties.—It is a solid at ordinary temperatures and pressures, melting at a temperature of 176° F. It will, however, exist in a state of vapor suspended in gas at temperatures far below even that at which it solidifies as long as the gas is not saturated with it. As soon as the point of saturation is reached the vapor passes directly into the solid state in the form of very light, flaky, flat crystals which occupy a large volume in proportion to their weight. It is this property which renders naphthalene so troublesome to the gas-manufacturer, since, though the weight contained in a given quantity of gas is small, the crystals occupy sufficient space to seriously obstruct the apparatus and pipes around the works and the services in which they are deposited through chilling of the gas.

Naphthalene obstructions in the apparatus and pipes at the works are usually removed either by flushing with hot water or by steaming, the former being preferable since the steam merely melts the naphthalene, and unless it can escape from the pipe at once it may cool down again and solidify in another part of the apparatus, while the hot water acts not only by melting the naphthalene, but also by carrying it along to a certain extent in mechanical suspension. It is well to use the water in considerable volume in order to secure this latter effect.

Naphthalene is removed from service-pipes and small mains by means of light naphtha, gasoline, or kerosene, which is poured into and allowed to run through the pipes, dissolving the crystals and carrying the naphthalene in a liquid form back into the mains and drips. Sometimes wood-alcohol is used instead of naphtha or kerosene. If the obstruction is very light it may be blown out of the service into the main by means of an air-pump, or even by the lungs.

Naphthalene in the form of crystals, like water in the form of ice or snow, will pass from the solid state directly into that of vapor, and thus naphthalene that has been deposited in the pipes in quantities too small to cause trouble and render it necessary to clean it away will evaporate again and pass off with the gas when this reaches the deposit in an unsaturated condition. This same naphthalene may be redeposited further along in the system if the temperature changes so as to bring the gas temperature again to the point of saturation with naphthalene, and it is probable that some action of this kind has given rise to the theory that naphthalene can be formed during distribution in a gas which was free from it when it left the holders.

Deposits.—Accumulations of naphthalene in the inlet-pipes of gas-holders occur most frequently in that portion of the pipe which passes down under the tank-wall and up inside the holder. When naphthalene exists in the pipe as a flocculent lining of approximately uniform thickness throughout a large portion of its length, it can be removed by charging the gas with the vapor of light naphtha, gas so charged being able to pick up naphthalene deposited in the form of loose crystals. The gas can be charged with the vapor either by injecting the naphtha into the inlet-pipe in the form of a spray, by means of a steam-jet, or by filling the drip at the bottom of the pipe with naphtha, which gradually evaporates into the gas passing over it. Naphthalene in the condition named can also be removed by blowing steam into the pipe in sufficient quantity to raise the temperature to the point at which the naphthalene will either melt and run down into the drip, from which it can be pumped out, or vaporize and

be taken up by the gas. In all of these methods it is necessary to have gas flowing through the pipes, so that the naphthalene as it is vaporized will be picked up by the gas and carried along with it out of the pipe, and there is always danger that the naphthalene so picked up will be again deposited at an inconvenient point during the further travel of the gas. When naphtha vapor is employed this will condense at the same time that the naphthalene is deposited, dissolve the latter, and carry it along to the nearest drip, thus preventing any obstruction, but when steam is used the liability is great that the obstruction will be merely transferred from one point of the pipe system to another.

In many cases the presence of naphthalene is not suspected until it has formed, on the inside of the portion of the pipe which rises through the water in the tank, a layer of such thickness that it is detached from the sides of the pipe by its own weight and falls into the elbow making the turn from the vertical into the horizontal part running under the tank-wall, where it forms a compact mass. Such a mass seems to be very little affected by heat or with naphtha in the liquid form. Hot water may be used in several ways. At one works, the water, heated by means of steam in an old boiler equipped for the purpose, the pressure being run up to between thirty and forty pounds per square inch, was conducted to the holder by a temporary line of pipe.

Removing Deposits.—The operation of cleaning out the holder-inlet was carried on as follows: The holder was practically emptied of gas, the time chosen being that when the stock of gas was small enough to be contained in the other holders, and kept so as long as possible, though this was merely to keep the weight of pipe to be handled at a minimum, as the holder could be raised through the outlet-pipe without interfering with the work. Through a hole drilled in the top of the bonnet over the inlet-pipe was inserted a one-inch pipe on the bottom of which was screwed a $1 \times \frac{1}{2}$ in. L, the direction in which this L pointed being marked on the pipe at the top. This pipe was made long enough at the start to reach down to the bottom of the holder-inlet, and a number of short pieces of pipe were provided to screw on as the holder rose. The pipe fitted loosely in the hole in the bonnet, but a practically gas-tight joint was made by wet cloths wound round the pipe at this point. The pipe was supported and turned by means of a bar handle clamped on at the proper height. A hose connection being made between this pipe and that from the hot-water heater, and the water being turned on, it issued from the opening in the L in a jet which broke up and dissolved the naphthalene and ran down into the drip, from which it was pumped, bringing the naphthalene with it both in solu-

tion and in suspension. The drip-pump was kept working all the time the hot water was being run in, so that the water should be pumped out before it cooled down and dropped the naphthalene. The water-pipe being turned so that the stream played against all parts of the inlet-pipe, a very complete cleaning could be given by this method.

Another method of washing out the naphthalene is called "plunging." In this the inlet-pipe is sealed with water, the flange at the top of the vertical pipe outside the holder taken off, and the drip-pump removed. The pipe is then filled as full of hot water as it is possible to have it without filling up the horizontal run coming to the holder from the station-meter. A plunger or wooden cylinder, about 18 inches to 2 feet long and a little smaller in diameter than the pipe, fastened to a pipe handle, the axes of the pipe and the cylinder coinciding, is then inserted and worked up and down, so as to impart a surging motion to the whole body of water. The surging back and forth of the water dislodges the naphthalene that is not dissolved, and the large pieces rising to the surface are fished out, the remaining fine particles being pumped out with the water. It is rather a difficult matter to get the large body of water contained in pipes above 6 in. in diameter moving with sufficient velocity to dislodge the compact masses of naphthalene; but if the motion can be produced, "plunging" is a very effective method for the removal of naphthalene from the pipes.

When naphtha or any other liquid solvent is used it is not economical to pour it into the pipe by itself, since if this is done it will cut channels in the deposit, through which it will run to the drip before it is fully saturated with naphthalene. A better effect can be obtained by pouring water into the inlet until it is filled to half its height. Then from four to five gallons of solvent naphtha are poured in and the water slowly pumped out at the drip, so that the liquid gradually falls in the main. The consequence is that the solvent, which forms a layer on the top of the water, is forced to act on the whole of the interior surface of the main, both where the latter is upright and where it is nearly horizontal. The time during which it acts on the surface is determined by the rate of pumping, and thus may be made sufficiently long to complete the solution of the naphthalene. When the solvent has reached the elbow, the rate of pumping is diminished in order to give it time to act on the greater horizontal section of the pipe which then becomes exposed to it. By this method of treatment the whole of the inner surface of the pipe is freed from naphthalene, which is completely removed from the main through the pumps.

Preventing Deposits.—The various methods employed or proposed to prevent the deposition of naphthalene in a solid state in the mains and services may be divided into two general classes, those which remove the naphthalene from the gas at the works by means of some absorbent, and those which consist in adding to the gas-vapors of liquids having a solvent action on naphthalene and approximately the same vapor tension as that substance.

Methods of the first class have been adopted quite generally on the continent of Europe and to some extent in Great Britain. In them the gas is washed or scrubbed with an oil which possesses the property of absorbing naphthalene vapor, the process being exactly similar to that by which the ammonia is removed from the gas. The operation is usually carried on in a rotary mechanical scrubber of the Standard type, in which either creosote-oil, heavy tar-oil, or anthracene-oil is used instead of water. A small amount of benzol, from 4 to 8 per cent. by weight, is added to the oil used, to saturate it and thus prevent it from absorbing benzol from the gas and reducing the illuminating power.

According to Dr. Bueb at Dessau, Germany, an anthracene-oil boiling between 480° and 750° F. is used, and 176.4 lbs. (19 to 20 gallons) of this oil removed, from 706,000 cu. ft. of gas, naphthalene to the amount of about 200 grains per 1000 cu. ft. The capacity of the oil for naphthalene increases with the temperature, and the naphthalene scrubber should follow the tar-extractor and work on comparatively hot gas. In some cases, however, two or three compartments of the ammonia scrubber are used. After being saturated with naphthalene the oil can be put in a still and the naphthalene driven off, or it can be chilled, crystallizing the naphthalene, which is then removed by means of a filter-press. In either case the oil can be used over again. If working on a small scale, it may be more economical to run the saturated oil into the tar-tank and sell it as tar.

The frequently employed method of running into the gas, as it goes out into the district, naphtha which becomes vaporized and travels along with the gas, belongs to the second class. The naphtha is usually added to the gas at the outlet of the governor, being blown into the gas in a finely divided spray by a small steam-jet atomizer. The success of this method depends upon the precipitation of the naphtha in liquid form at the time and place at which the naphthalene is deposited, so that the latter will be dissolved and carried off by the former, and as this does not always occur the remedy is not always successful.

A modification of the above method, known in English as the Hastings carburation process, consists in forming in the gas as

it goes out from the works into the street-mains a mist of oil, the oil used being one that is not volatile at ordinary temperatures. This mist, in very minute drops, is formed by blowing the oil through specially constructed atomizers by means of a portion of the gas, which is compressed to a pressure of 75 lbs. per square inch. It is found that in this state of minute subdivision some of the oil will remain in the gas until it reaches the farthest point in the district; the conditions which will cause the deposition of naphthalene at any point will also precipitate enough of the oil to dissolve this naphthalene and carry it off as a liquid. It is stated that at Hastings one gallon of oil used in this way for each 166,000 cubic feet of gas is sufficient to do away with all trouble from naphthalene stoppages, although these begin to show as soon as the process is discontinued.

Much information on the subject of prevention of deposits of naphthalene in street-mains and services can be found in Vols. LXXII to LXXVI of the *Journal of Gas-lighting.*

According to Dr. Paul Eitner, in the *Journal für Gasbeleuchtung*, Vol. 42, p. 89,

One gram of benzine will dissolve

0.32 grams of naphthalene at	32° F.
0.407 grams of naphthalene at	50° F.

From tables of the vapor tensions of benzine and naphthalene it is found that

One cubic foot of gas can take up

3.25 grams of benzene at	32° F.
5.72 grams of benzene at	50° F.
9.45 grams of benzene at	70° F.

One cubic foot of gas can take up

0.0005 grams of naphthalene at	32° F.
0.0045 grams of naphthalene at	50° F.
0.0155 grams of naphthalene at	70° F.

These figures show that gas, if saturated, can carry 2000 times as much benzene as would be required to dissolve the largest amounts of naphthalene the gas can hold at 32° F.

Oil-tar, after being separated from oil and entrained water, is suggested as a remedy for naphthalene, the gas being scrubbed through it in the same manner as with anthracene oil, when it will absorb about 25 per cent. of its own bulk of naphthalene.

A Continuous Naphthalene Test may be arranged as follows:

Dissolve 150 grains picric acid in one quart warm distilled water. Bubble 1 ft. to 1½ ft. gas per hour through 100 c.c. of this solution. If gas contains an excess of naphthalene, a heavy precipitate will appear. Avoid use of rubber tubing in making test.

If gas contains tar, filter through a tube containing cotton. Tar will color solution brown and prevent naphthalene precipitate forming.

If gas contains an excess of ammonia —say more than 5 grains—bubble gas first through 5 per cent sulphuric-acid solution. Ammonia will color the acid red-brown and prevent precipitation. One or more of the absorption bottles like that represented in Fig. 28 may be used.

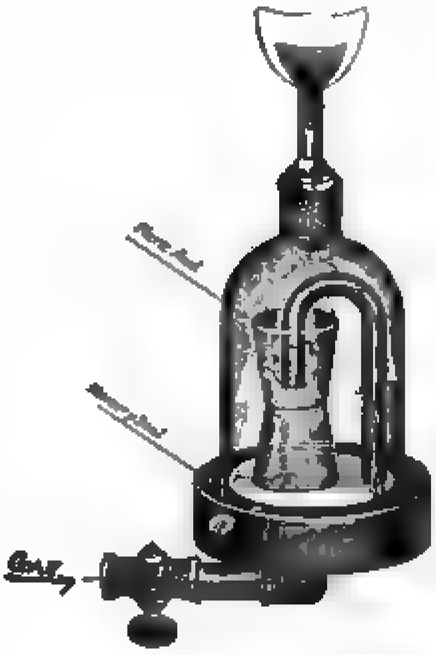


Fig. 28.

CHAPTER XIII.

MAINS.

Capacity.—The gas-consumer is connected with the gas-supply in the works holder by underground pipes or mains with their branches and service-pipes. These pipes are generally of cast iron, although in the natural-gas districts steel screw-joint pipe is largely used, and the connections to services are made by tapping into the top or side as preferred. The formula for calculating the capacity of cast-iron mains was given by Clegg and attributed to Pole, being known as Pole's formula, and is stated as follows:

$$V=1350\sqrt{\frac{d^5h}{gl}},$$

where V = cubic feet delivered per hour into atmospheric pressure;
d = internal diameter of the pipe in inches;
h = pressure on gas at entrance in inches of water-head;
g = specific gravity of the gas, air = 1;
l = length of pipe in yards.

The constant 1350 is arrived at when considering a fixed friction derived from very old experiments. Some engineers assume this figure only for pipes 10 in. or over in diameter, taking 1250 for 6- to 10-in. pipes and 1000 for pipes under 6 in. diam. This formula is of course applicable to low-pressure distribution only. When higher pressures are employed, such as exist in high-pressure distribution or natural-gas practice, a formula must be employed taking into consideration both entrance and terminal pressures, influence of compression and temperature, such as that developed by Professor Robinson:

$$V=48.4\frac{T_s}{\sqrt{T_2T_0}}\sqrt{\frac{d^5}{L}(p_1+p_2+30)(p_1-p_2)\frac{.6}{g}},$$

where $T_0 = 461 + 37 = 498$ deg. F., the absolute temperature at the maximum density of water;
T_1 = absolute temperature of gas after delivery (461 + deg. F.);
T_2 = absolute temperature of gas in the main;
d = diameter of the pipe in inches;
L = length of main in miles;
p_1 = initial and
p_2 = terminal gage pressure in lbs. per sq. in., and
g = specific gravity of the gas transmitted (that of natural gas being 0.6).

The Cox gas-flow computer, a slide-rule device, was calculated from this formula:

$$V = 33.3\sqrt{\frac{d^5}{Lg}(P_1{}^2 - P_2{}^2)},$$

where P_1 and P_2 are the initial and terminal pressures absolute (14.7 + gage pressure) in lbs. per sq. in. A more accurate determination by actual test is made by the Pitot tube, described in the chapter upon Pressures. J. D. Shattuck in 1905 made a report upon the various formulas for this purpose to the Ohio Gaslight Association, subsequently published in *Progressive Age.* In comparing the capacities of mains it is thus seen that this varies as the square root of the fifth power of the diameter.

Laying Mains.—The depth at which mains should be laid should depend upon two conditions, namely, climate and the protection of mains from the crushing stress of heavy traffic. It is customary, with regard to climate, to place the top of the pipe below the nominal frost-line, which varies from 6 ft. in Canada to some 24 in. in the Southern States. For ordinary purposes, however, 30 in. below the ground generally gives satisfactory results. Such laying, however, depends somewhat upon topography and local conditions, such as the presence of sewer-lines and -services, water-mains, etc. It is necessary, of course, to lay pipe upon a grade sufficient to completely drain it, and it is economical and good practice to lay as long a line as possible without putting in drip-pots. As an offset, however, to this is the increased expense of ditching not only in the initial installation, but the subsequent laying of service-lines.

The writer strongly advises that at no time shall a smaller size of cast-iron pipe than 4 in. diam. be laid. There are occasions where districts will not require a larger size than 3 in. for an indefinite period, but these are rare and generally can be supplied by long services of wrought-iron pipe.

A good average weight for 4-in. cast-iron pipe is 220 lbs. per length of 12 ft., or in the neighborhood of 18 lbs. per ft. A lighter pipe than this is not advised, as it is impossible to anticipate what crushing stress it may have to endure, to say nothing of the advantage of strong bells for calking.

Specifications for various classes of cast-iron pipe and fittings, as designed by the Committee on Research for the American Gaslight Association, are appended to this volume.

Gradient.—The minimum grade permissible for draining mains should certainly in no instance exceed one inch per 100 ft.

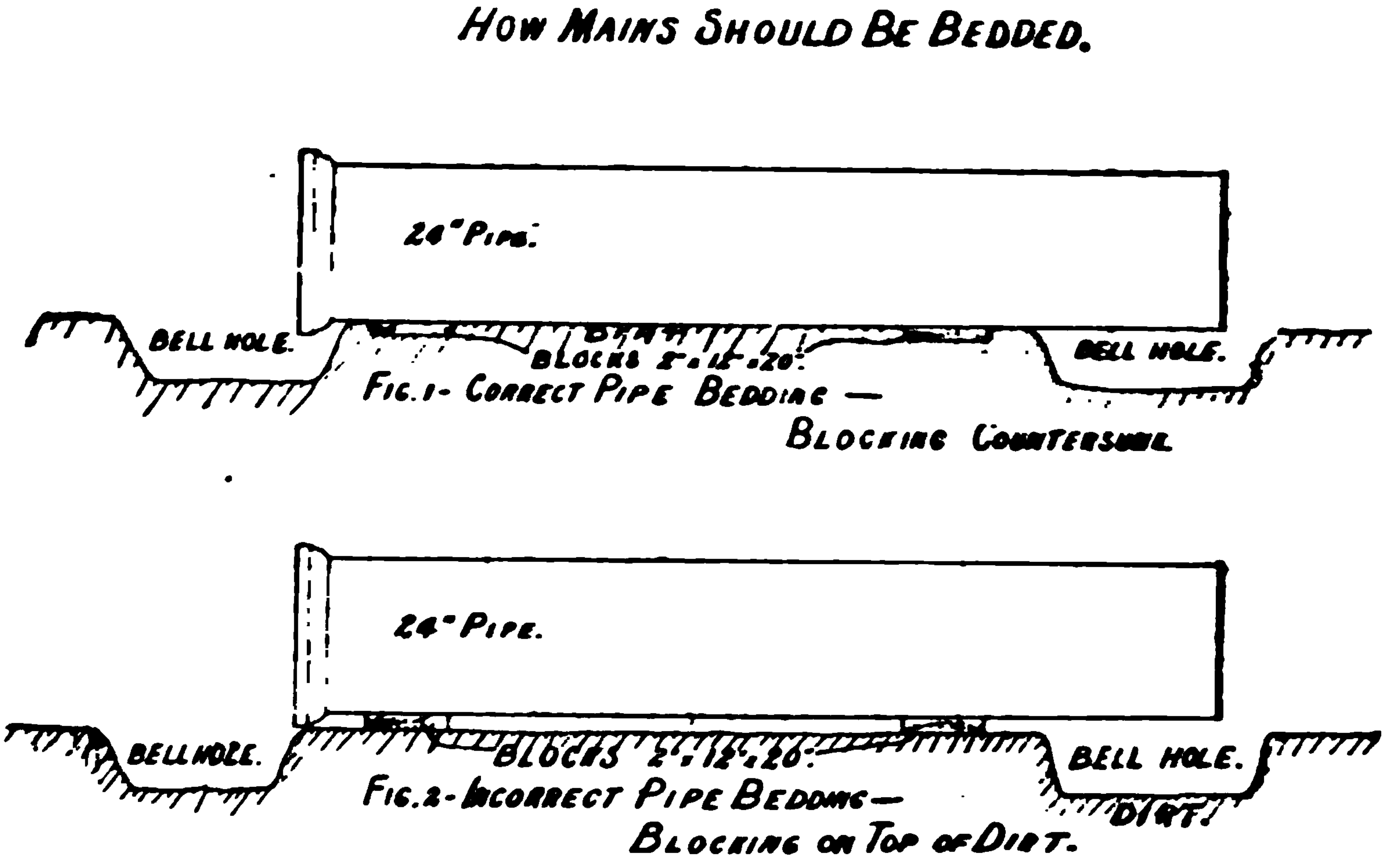


Fig. 29.—Proper Method for Laying Mains in Trench.

of main. This, however, is about the minimum permissible in a sewer. Where a greater hydraulic head as well as hydraulic radius is obtained, the hydraulic radius in gas-mains is so exceedingly small and the viscosity of the condensation (composed largely of tar and other oily ingredients) is so great that better practice suggests a fall of at least a quarter of an inch, or better 0.318 in. per length of 12 ft. of pipe. This is more necessary in low-pressure mains than in high pressure, the latter having less condensation and the velocity of the gas tending to free the main from liquids collecting in trapped portions.

Where the soil is bad and shifting, the bottom of the ditch should be blocked. This should be done in any event where the size of the pipe exceeds 18 in. diam. These blocks, usually 2×12×20 in., should be below the level of the bed of the ditch, as per Fig. 29, the whole surface presented to the pipe being

flush and forming a continuous bearing for it. The same gradient or fall of the pipe is maintained throughout.

District mains should be invariably laid with an allowance for extension of business, and the calculation should be based upon a system, which, when loaded to capacity, would not show a pressure drop at the moment of peak-load in excess of 25 per cent., 20 per cent. being better practice.

Pipe-joint Specifications.—The following are the specifications of the United Gas Improvement Co. of Philadelphia, for the making of lead joints: "Each spigot end should be driven home into the bottom of the bell, the joints should be well calked with jute packing, the greatest care should be taken that the packing is calked as solid as the yarning-iron and heavy hammer will calk it. This joint in itself should be gas-tight. The calking should be done evenly, so that all parts of the joint will be evenly solid. The lead should be of the best quality of soft lead and the amount required per joint approximately as follows:

3-in.	pipe	about	2¾	lbs.	lead.
4-in.	"	"	4	"	"
6-in.	"	"	7	"	"
8-in.	"	"	10	"	"
10-in.	"	"	14	"	"
12-in.	"	"	18	"	"
16-in.	"	"	28	"	"
18-in.	"	"	32	"	"
20-in.	"	"	35	"	"

"The weights given above have been found to be sufficient if the yarning has been properly done. The lead should be evenly, gradually, and thoroughly calked, so that when finished all parts of the joint will be of an equal degree of hardness. In no case should a joint be completely calked at one part before the other parts of the joint are taken in hand.

"In laying mains, when it is required to turn a corner, or to make a bend for any purpose, elbows or specials should always be used. It is bad practice to make a bend by making each joint give a little and thus dispensing with the use of a special. Quarter bends and eighth bends can be always obtained, and special angles can be made by the use of circle bends. These specials can be cut so as to obtain almost any required angle.

"Great economy will result from the proper handling of the ditch or trench in which main is to be laid. The earth, stone, gravel, etc., should be separated upon being excavated with large forks, each according to its kind, and in back-filling should be re-

laid in strata, the large stones first, then smaller stones, and finally gravel with the dressing of loose earth, each stratum being separately and thoroughly tamped into place. This back-filling, when properly done, will not settle and leave a depression in the street.

"No larger ditch or trench should be excavated than is actually needful for the size of pipe to be laid. An approximate table of the width of a trench for various sizes of pipe is herewith given.

4-in.	diameter,	width	20 in.
6-in.	"	"	22 in.
8-in.	"	"	24 in.
12-in.	"	"	30 in.
16-in.	"	"	35 in.
20-in.	"	"	40 in.
24-in.	"	"	44 in.
30-in.	"	"	50 in.
36-in.	"	"	56 in.

In excavating the bottom of the trench should be carefully graded and bell-holes made at intervals of 12 feet. The bottom of the ditch shall be such as to give a continuous and positive bearing for the main.

"In running lead joints, standard pipe being used, the spigot end being first rammed home, the space formed by the junction of the spigot and bell shall be filled and calked with strands of tarred oakum until the space is filled to give the lead depth required for the size of pipe, and driven up sufficiently tight to cause the yarning to spring back when impinged. This lead depth to be left in the bell should vary with different sizes of pipe and should be about as follows:

4-in.	diameter	pipe,	lead	joint	to	be	$1\frac{1}{2}$	in. deep.
6-in.	"	"	"	"	"	"	$1\frac{1}{2}$	" "
8-in.	"	"	"	"	"	"	$1\frac{3}{4}$	" "
12-in.	"	"	"	"	"	"	$1\frac{3}{4}$	" "
16-in.	"	"	"	"	"	"	2	" "
20-in.	"	"	"	"	"	"	$2\frac{1}{4}$	" "
24-in.	"	"	"	"	"	"	$2\frac{1}{4}$	" "
30-in.	"	"	"	"	"	"	$2\frac{1}{2}$	" "
36-in.	"	"	"	"	"	"	$2\frac{1}{2}$	" "

All joints when run should be flush with the face of the bell, and should they be driven up in calking more than $\frac{1}{8}$ in. they should be re-run.

"All joints should be invariably tested before joint-holes are

back-filled. It is best where feasible to test long sections of pipe by pumping up an air pressure, using a pressure-gage and noting loss of pressure due to leakage. The test pressure should not be less than 5 lbs. per sq. in. (10 in. of mercury). But where this method is impossible each joint should be covered with heavy soapsuds while under gas pressure and an examination made for bubbles.

"It sometimes becomes necessary to use a split sleeve in the case of a broken main, although its use is to be avoided. When used, however, it is an invariable rule that the two ends of the pipe should be bound together by wrapping with unbleached muslin or canvas, a mixture of red lead and white lead being spread in the folds of the cloth, the whole securely wrapped with strong twine or cord, and coated with shellac. The width of the wrapping should be such that the sleeve projects on either side at least 2 inches. After this is completed the split sleeve is to be applied, care being taken that there should be no leak at the flanged joint. It is sometimes necessary if the flanges are not faced that the joint between them should be made with tar board which has been softened by soaking in warm water. It is better, however, to face them by grinding them upon each other with fine emery powder.

"It is well to purchase all cast pipe and specials uncoated, varnished, or tarred, as defects in the casting, sand-holes, etc., are frequently concealed in this manner, even to the temporary standing of gas pressure, but in the long run such stoppages will give way and leaks occur.

"When it is necessary to work upon a broken main, etc., in frozen ground, it is convenient to thaw the ground in the following manner: A recess 6 or 10 inches deep is dug over the section of main to be worked on, and of the desired length. This is filled with a good quality of unslaked stone lime and several buckets of water thrown thereon. The recess is then covered closely with old cement sacks and boards and left for several hours. In this manner the frost can be drawn from the ground for a considerable depth.

"When it is necessary to cross a bridge with a gas-main, the practice should be to run from the lower level in the street to the upper level on the bridge a pipe of larger diameter than the pipe to which it is connected; for instance, let A = the main and V = the risers and specials crossing the bridge, then when a main is 3 in. it requires the riser to be 6-in. diam.; for A 4 in., B must be 8 in.; a 6-in. main requires a 10-in. riser; an 8-in. main a 12-in. riser; a 10-in. main a 14-in. riser; a 12-in. main a 16-in. riser, and a 16-in. main a 20-in. riser. Should the pipe crossing the bridge

be exposed, expansion joints should be placed on either side to take up vibration and change of temperature.

"All records of drips and valves should be carefully kept not only in a file index, but also entered upon the company's map, and extensions and changes corrected thereon and kept up to date."

The following paragraph, taken from the gas educational trustees of the American Gaslight Association, cannot be too forcibly urged upon the attention of engineers and foremen:

"In the laying of street mains it is of the utmost importance to see that all pipes are on a slight incline or gradient, so as to drain all condensation to a given point which is situated at the lowest part of the main, where all the condensation is collected by means of drip-wells. If the pipes are not laid on a perfect gradient there would be a collection of water in the various parts of the pipes where sags or traps occurred, which would hinder and stop the flow of gas according to the depth of the trap and the amount of water therein."

For all sags in the pipe-line, drips, or traps, proper drip-pots, such as described in the standard specials of the American Gaslight Association, should be provided.

Cement Pipe-joints.—The following information upon this subject will be found in the Proceedings of the American Gaslight Association:

"The cement joint for street mains is cheaper than the lead joint. It is more rigid, and under changes of temperature is more apt to remain tight. The lead joint is more easily cut out than the cement joint, more easily repaired, and has the advantage of 'coming' and 'going' with the changes of temperature, which, in the case of the cement joint, might fracture the pipe." (See Vol. 13, p. 47.)

"The joints commonly employed in this country for connecting together the separate lengths of cast-iron pipes are the lead joint and the cement joint. The lead joint, while, as a rule, more expensive than the cement joint, has the advantage of being more easily cut out, more easily repaired, and of allowing the pipes to expand and contract, under the influence of changes of temperature, without fracture, since the lengths can move in the joints. On the other hand, the cement joint is cheaper and more rigid than the lead joint, and when properly made will remain tight under almost any possible conditions. A line of pipe laid with cement joints if exposed to changes of temperature will not show small leaks at the joints as will one laid with lead joints, but, on the other hand, it will probably be fractured in one or more places. In most instances the choice between lead

and cement joints is determined by the relative disadvantages of a number of small leaks, no one of which is large enough to be dangerous, and one large leak, which, though it will be quickly detected, may cause great damage before it can be repaired. In one large city lead joints are used in the heart of the city, where gas from a large leak would be apt to accumulate in cellars, sewers, and electrical conduits, with danger of disastrous explosions, and cement joints are used in the outskirts, where the conditions are favorable for the gas from a leak passing away into the open air without forming an explosive mixture in any confined spaces." (See Vol. 17, p. 137.)

"Use Portland cement. Natural cements are not uniform in quality, and, as a rule, are too quick-setting to permit of their use with safety. In selecting the brand, take a relatively quick-setting Portland. If the cement sets too slowly there is danger of the finished joint being disturbed before setting. Use the cement neat—no sand. Use the cement as dry as possible, so that it requires hammering the yarn against it in order to bring the moisture to the surface. When sufficient water is added the cement will still appear crumbly in the pan, and will just retain the impression of the fingers when squeezed in the hand. The cement should be used immediately after mixing, only enough being mixed at one time for, say, two joints; if it lies unused over five minutes, it should be discarded. The cement remaining in the pan should be entirely removed before mixing

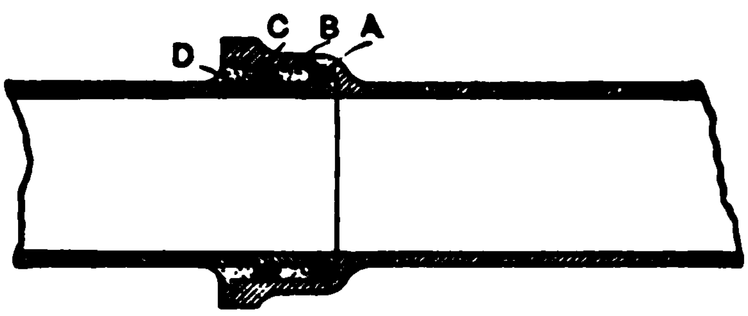


Fig. 30.—Cement Joint.

up any new cement. In mixing cement, first determine the quantity required for one joint, and the quantity of water required for this cement, and then always use the cement and water by measurement. Use jute yarn, untarred. When the joint is made the yarn and sides of joint may be moist or damp, but should not be wet (Fig. 31). The finished joint should consist of one roll of yarn (*A*) of the exact circumference of the pipe, twisted and driven tightly to the bottom of the bell; then a solid mass of cement (*B*) extending to a point about 1.5 in. back of the face of the bell; then a second roll of yarn (*C*); then

a facing of cement (*D*). Do not make a large fillet extending to the outside diameter of bell. In entering the cement be very careful to completely fill the whole space. A wooden pusher shaped something like a yarning-tool is useful for pushing back the cement after it has been entered by the hand. Sometimes a roll of yarn is used to drive the cement back, the yarn being withdrawn, more cement entered, and the process repeated until the desired quantity has been entered. After the first yarn is in, and before the joint is made, the pipe should be thoroughly bedded and tamped in between the bell-holes, to prevent any movement of the joint after it is made. When the joint is made, it should be protected from the sun. As few joints as possible should be made in the rain. All joints should be tested before being covered up. The test is made by connecting gas pressure to the new pipe through a meter, thus measuring the amount of leakage, if any. If the meter indicates leakage, the holes should be found by using soap-suds on the joints. Fire should never be used. Better still, an air-pump and mercury-gage may be employed. The joints should be tested only after the cement has set sufficiently to prevent its being hurt by the soap-suds; where feasible, this should be on the following day.

"In the sketch (Fig. 31) is a side view of a 6-in. cement joint, with part of the hub removed, showing cement and packing. In the sketch *C* is the cement, *P* packing. After the pipe has been 'sent home' graded, and the joint equalized as near as possible, 1 in. of hemp packing is firmly driven in as shown in the pre-

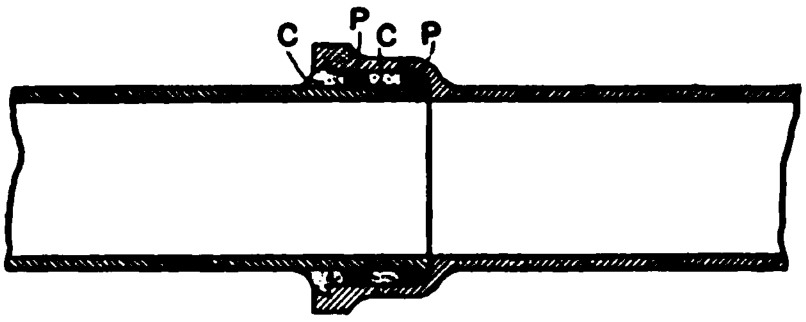


FIG. 31.—Another Form of Cement Joint.

vious illustration; then 1 in. of cement and 1 in. more of packing, followed by 1½ in. of cement, of which ½ in. is on the outside of hub, and slopes from center of rim down to pipe as shown. To make this joint requires 3½ pounds of cement and sand mixed dry—2 parts of cement to 1 of sand—and 3 ounces of hemp packing. The joint can be made in 15 minutes."

Lead Pipe-joints.—"In making a lead joint in 6-in. cast-iron main, the first step in the operation, after the spigot end of one length has been inserted in the bell of the other and the length driven home, lined up, and fixed in place by the tamping of a

little dirt around the middle of it, is to fill solidly with packing a portion of the joint space between the spigot and bell, the amount of space so filled being determined by the depth of lead which it is desired to have. For ordinary straight work with 6-in. pipe the depth of lead may be taken at 1.5 in., and the joint space will therefore be filled with packing to a point 1.5 in. back from the face of the bell. Jute packing, either plain or tarred, is usually employed. Packing which has been allowed to absorb a small quantity of tar can be driven tighter than plain packing, but, tar being cheaper than jute, it is hard to avoid the presence of too much tar in tarred packing, and for this reason plain packing is often given the preference. A sufficient number of strands of packing should be twisted to form a rope of a diameter a trifle larger than the width of the joint space, and this should be cut into pieces of such length that the end will come into close contact when a piece is placed around the outside of the spigot end of the pipe and pulled up tight. One of these pieces is used to lift the spigot end as it is inserted into the bell of the pipe previously laid, and is sent home with it, thus keeping the spigot central in the bell and avoiding the necessity of wedging it up after it is in place. This piece of packing is driven solidly into place in the bottom of the joint space by means of a calking-hammer and packing-iron, and other pieces are inserted one at a time, the joint in each ring being put say one-fourth of the circumference away from the joint in the preceding ring, and each driven home, a sufficient number being used to fill the joint space to the required depth, leaving 1.5 in. for the lead. The packing must be driven hard and the finished layer must be of uniform depth, so that the lead space will be uniform all around the pipe. A clay roll or other form of joint runner is then placed around the spigot end of the pipe, being brought tight against the face of the bell, and so set as to leave a triangular space, having its base on the pipe and its apex on the face of the bell slightly above the inside edge, which the lead can fill and thus make it certain that when driven the joint will be of the shape shown in the cut. Molten lead is run into the joint and this space until both are completely filled and the lead stands above the highest point of the inside edge of the bell, the lead being poured in through an opening or 'gate' left on top of the pipe. When the lead has hardened the joint runner is removed, and the 'gate' or lump of lead where the opening for pouring was made is cut off. The lead is then chiseled all around the pipe with a cold chisel and calking-hammer. This separates the lead from the surface of the pipe, and makes a groove in which the first calking-tool, the face of which is about $\frac{3}{16}$ in.

thick, can fit. The lead is driven all around with this tool and then with tools successively increasing in thickness about ⅛ in. until the full width of the joint has been reached. The work with each tool should be begun at the bottom of the pipe and carried around each way, finishing up at the top. The thickness of the last tool used should not be greater than the width of the joint, and the driving with this tool should cut the lead off sharp with the inside edge of the bell, otherwise there is danger that the force of the blows will be expended against the face of the bell instead of doing the full amount of work that it should do in compressing the lead in the joint. In order to have the tools fit the joints exactly it is well to have them made in sizes varying in thickness by $\frac{1}{16}$ in., though it is only necessary to use on any joint tools varying by ⅛ in., the proper sizes being selected. The position in which tools are naturally held when calking the joint will give it the finished shape shown in the cut, if the joint runner has been put on properly and sufficient lead used. There will be required for making a 6-in. lead joint about 7 to 8 lbs. of lead and 7 to 10 oz. of jute packing. A good workman should be able to average nearly 3 joints an hour for a day's work."

TABLE OF CEMENT AND YARN REQUIRED, AS PREPARED BY VON MAUR, 1905.

Size of Pipe.	Cement in Quarts.	Cement in Pounds.	Water in Pints.	Yarn in Ounces.
4″	1 to 1½	2.25 to 4.10	⅘ to 1⅓	4
6″	1½ to 2	4.10 to 5.50	1¼ to 1⅝	6
8″	2 to 2½	5.50 to 6.87	1¼ to 1½	8
10″	2½ to 5	6.87 to 8.25	1½ to 2	10
12″	3 to 4	8.25 to 11	2 to 2½	12
16″	4 to 5	11 to 13¾	2¼ to 2½	15
20″	5 to 6	13¾ to 16½	2½ to 3½	20
24″	8 to 8½	20 to 23	5 to 5½	27
30″	7 to 7½	19 to 21	4 to 4½	27

Advantages of Various Joints.—"In England and on the continent of Europe a great variety of joints for cast-iron pipe have been devised and to a certain extent used. These include movable flange joints, clip joints, collar joints, screwed joints, bell-and-spigot joints in which the joint is made by means of a vulcanized rubber ring, and bored and turned joints as well as the fixed flange joints, bell-and-spigot joints of lead or cement, and ball-and-socket joints, which are practically the only joints used in this country, and are therefore the only ones considered in this article. Flange joints allow of an easy removal, when desired,

of any one of the various pieces of pipe. They are, however, very rigid, and their use is confined to lines of pipe above ground and at the works. On long, straight lines of flanged pipe one or more expansion joints should be provided to relieve the pipe of the strains that would be thrown upon it by its expansion and contraction under the influence of changes in temperature. Ball-and-socket joints are expensive and are used only for lines where great flexibility is necessary, as in laying pipes under water.

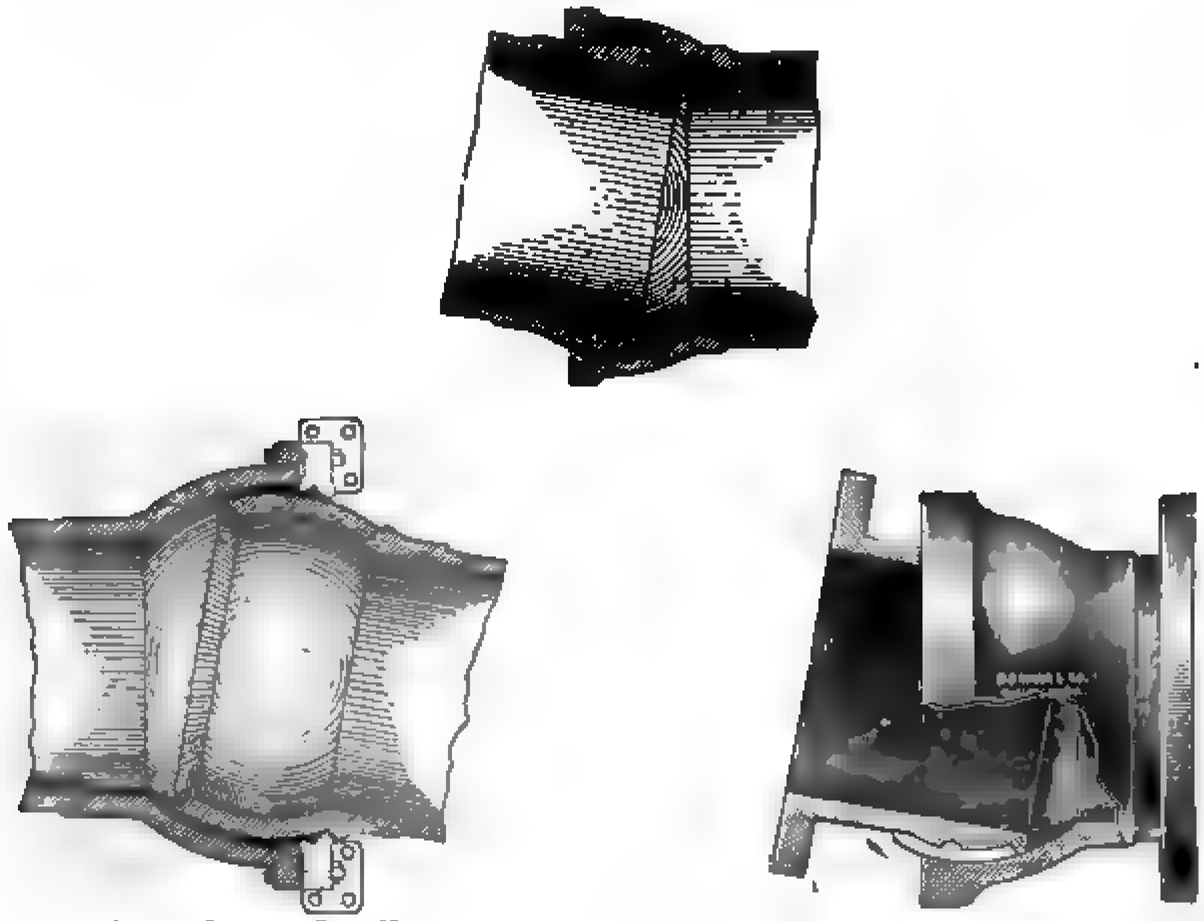


FIG. 82.—" Cup-and-ball " or swivel joint, especially used in crossing rivers, or any occasion where it is necessary for the pipe to " flex."

Disjointing Cement Joints may be most easily effected by the heating of the pipe bell and joint, after the fashion of melting out lead joints.

Cement joints should never be made in pipe recently exposed to the sun, without first reducing the temperature of the pipe to that of the atmosphere by wet cloths or water. The fresh joint should be protected from the heat or cold by shrouding it in wet or dry burlap or bagging respectively.

In cement joints untarred yarn is to be preferred, making a more homogeneous joint.

Combination Joints.—A frequent practice is to lay the pipes with cement joints, except at intervals of from six to twelve lengths, where a lead joint would be put in to act as

an expansion joint—the location being marked and noted, and the lead joint occasionally examined. This should make cement-jointed pipe practically as free from liability to fracture as lead-jointed lines."

The whole secret of success in joint-making lies in the yarn and calking. Every yarn joint should be in itself perfectly gas-tight, and every joint yarned or finished should be driven up perfectly tight with the calking-tools. The first requisite of cement joints is that no more cement should ever be made *than is to be used within five minutes*, all of the remaining cement being thrown away and discarded, as after that time the setting has begun to take place.

In the smaller sizes of pipe, where it is inadvisable to use a chisel in cutting, roller cutters, such as the Hall, manufactured by the Walworth Mfg. Co. and the Rodefeld Mfg. Co., may be found advantageous. The rollers in these cutters may be removed, retempered, and sharpened.

It should be remembered as the basal principle of all cast-iron pipe-joints, whether lead or cement, that the first yarn driven should be of itself independently "gas-tight." If this work is properly executed, the yarn being tightly calked and conscientiously worked over, the material subsequently used is a matter of secondary importance.

High-pressure Pipe-joints.—In laying high-pressure mains, which should be of extra heavy wrought-iron or steel pipe, where the usual coupling is used, it is good practice, after carefully lubricating the joints, to make up four or five sections of pipe hand-tight, when the whole may be screwed up with a power-winch. This should be done so that each joint is turned to a point where the threads completely disappear within the socket or coupling, and the whole will be found not only a most effective joint, but capable of extraordinary speed in execution, thereby greatly facilitating and expediting the labor of main-laying.

For the taking up of bends in the pipe, obviating the effects of imperfectly calked joints, and to reduce the electrolytic damage of current jumping around the joint, a pipe has been designed, under the name "Universal," in which the hub and spigot ends are machined to fit tightly without any packing whatsoever. The method of bolting sections together by flanges and a section of the joint are shown in Fig. 33.

Fig. 34 illustrates not only how to allow for the extra length caused by the joint, but also, by the use of short pieces and a nipple, how any desired length may be obtained.

For ordinary pressure Universal joints should not be drawn close up. When ordering pipe for exact measurements allow, in

addition to the pipe lengths, for each male end as specified in the table below, which gives the average exposure of the joint when made up as represented by letter *A* in Fig. 34.

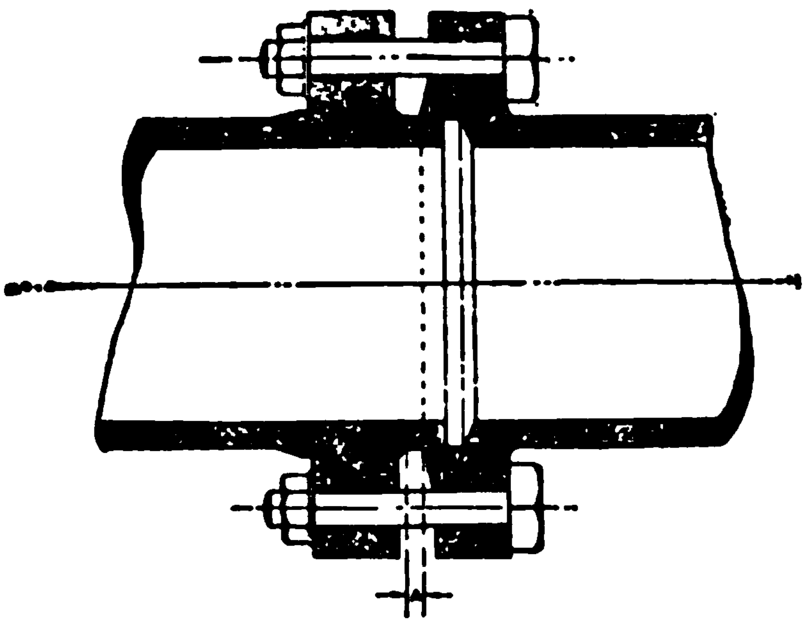


FIG. 33.—Universal Joint.

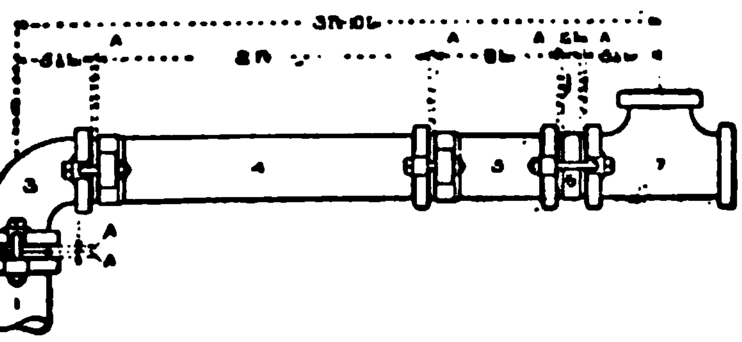
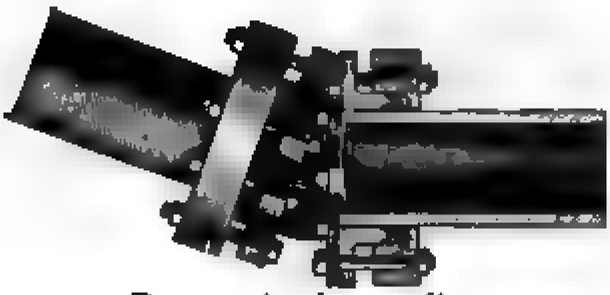


FIG. 34.—Universal Joint Connections.

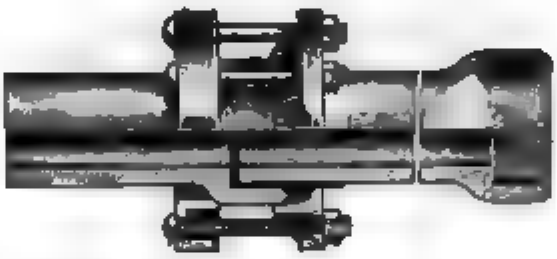
1, the hub end of a 4-in. pipe; 2, 4-in. close nipple; 3, 4-in. elbow; 4, 4-in.×2-ft. pipe; 5, 4-×9-in. pipe; 6, 4-×1½-in. space nipple; 7, 4-in. tee; *A*, ¼ in., which is the exposed part of the joint.

Diam. Pipe, Inches.	Averaged Exposed Portion of Joint represented by *A*, Inches.
2	$\frac{3}{16}$
3	$\frac{3}{16}$
4	$\frac{1}{4}$
5	$\frac{1}{4}$
6	$\frac{5}{16}$
8	$\frac{3}{8}$
10	$\frac{3}{8}$
12	$\frac{3}{8}$
14	$\frac{7}{16}$

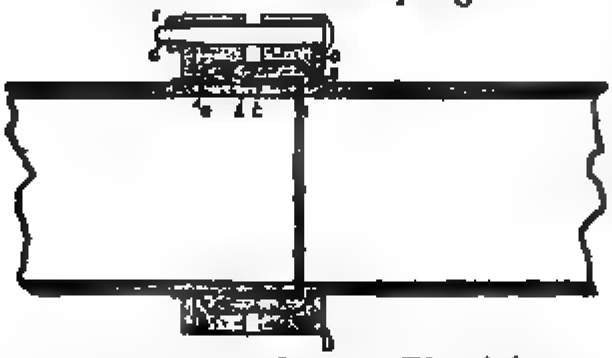
The following are some of the usual forms of high-pressure pipe-couplings:



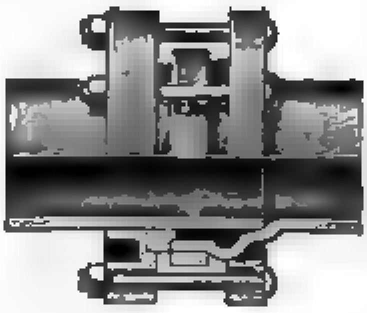
Dresser Angle-coupling.



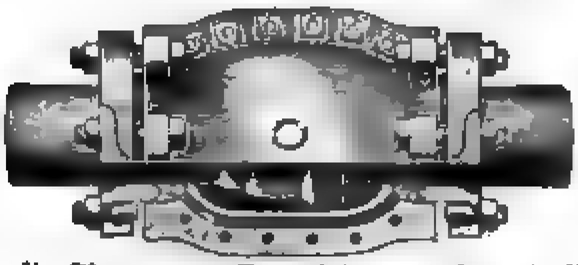
Insulating Coupling, Style 10, for Special or Dresser Style, Cast-iron Pipe.



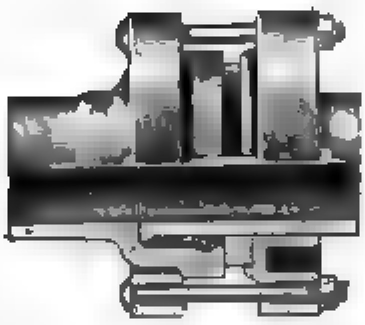
Section of the Dresser Pipe-joint.
A, spigot; *B*, V-shaped bell of pipe; *C*, cement, *D*, malleable iron ring; *F* and *G*, bolt and nut; *H*, asbestos ring; *R*, rubber ring.



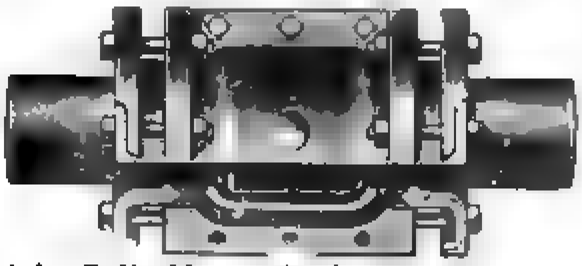
Clamp for Matheson Joints.



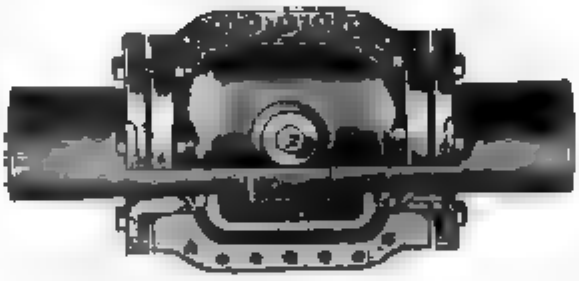
Split Sleeve for Repairing Broken Bell on Cast-iron Pipe.



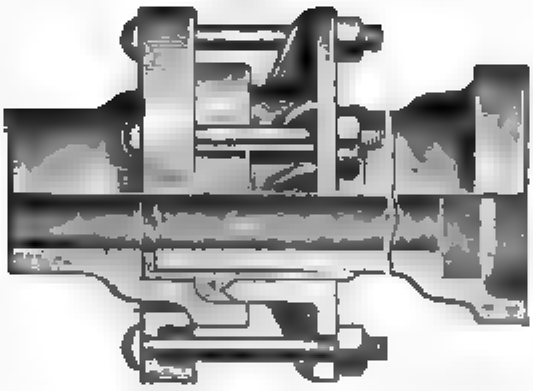
Clamp, Style 4½, for Repairing Leaks on Regular Hub and Spigot Cast-iron Pipe-head or Cement Joints.



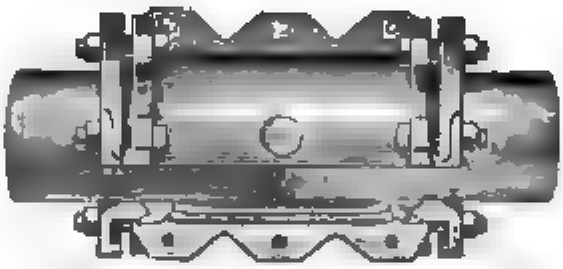
Light Split Sleeve, Style 13, for Repairing Wrought-iron Pipe.



Split Sleeve, Style 12, for Wrought-iron Pipe. Large enough to go over Dresser Coupling in Case of Accident.



Insulating Coupling for Dresser, Style 9, Cast-iron Pipe.



Split Sleeve for Repairing Broken Cast-iron Pipe.

Fig. 35.

Although high-pressure service merely exaggerates the conditions of low-pressure transmission, the increased duty is so severe and these conditions so strongly emphasized as to make necessary and essential a perfection of engineering, material, and workmanship which would in more or less degree be otherwise commercially dispensable.

The pipe used in high-pressure work should be extra heavy iron or steel, and of the best quality of meter, with the closest approximation to an equality of texture throughout, free from chilled spots, cores, sand-holes, etc.

The threads *should be taper* and constitute the best order of machine work, which threads in the transportation, assembling, and fitting of the pipe should receive infinite care, to prevent bruising, chamfering, or stripping. These threads should be carefully examined by a competent inspector immediately before "making-up," all pipe with defective threads being discarded, their threaded section being cut off and the threads re-run. Although this may seem an extravagance, it is in reality economical practice, and should be adhered to without deviation.

The quality of valves, cocks, fittings, etc., is also most important.

Commercially speaking and to all practical purposes, the quality of brass varies between two extremes. its highest refinement and efficiency being reached at an approximate composition of red brass consisting of 90 parts copper, 10 parts tin, and 2 parts zinc, while at the other or opposite extreme we find a yellow brass as low as in copper, as 50 parts copper and 50 parts zinc. The various grades and qualities of brass, commercially used and for the manufacture of fittings, lie between these extremes, although the former is occasionally and the latter frequently reached.

Red brass of the composition named attains a tensile strength of 68,000 lbs. per square inch, while the yellow alloy runs as low as 10,000 lbs. per square inch tensile strength, the various compositions and formula now in commercial service varying between these extremes very exactly in ratio with the preponderance of copper and the amount of tin and zinc.

As the proportion of lead, zinc, and tin becomes higher and the preponderance of copper less in the mixture obtained each ingredient preserves more distinctly its individual characteristics and attributes.

Going from red to yellow brass, the tendency is to revert from the close-grained tenacious copper to the spongy zinc. In alloying elements of such widely varying gravities as copper, lead, and tin, when such elements are in a molten state some separation or segregation must take place, the heavier metals going to the bottom of the molten mass in the order of their respective weights. It is

necessary to overcome this tendency by a certain amount of agitation; if this is incomplete, the result is an unequal distribution of the elements throughout the admixture. This condition tends to destroy any possible homogeneity in the structure and fiber of the resultant casting, and such inequality in the metal causes rapid excoriation, unequal grinding, as well as scoring of working parts and bearings where they meet.

If we take two fittings, one a red and another of the yellow metal, and place them on an anvil, striking them in succession with a sledge-hammer, using the same degree of force, it will be observed that while the red-brass casting may become slightly distorted, the brittle yellow-brass casting will fly in pieces. This is due to the extreme tenacity, ductility, and elasticity of the red brass obtained from its copper component, a peculiarity which the writer has observed in fittings during experiments with the Barrett pipe-forcing jack. In a number of instances where obstructions were encountered, under the enormous amount of pressure from the jack, the fitting was completely distorted without breaking, but, even in its distorted condition, preserved its tightness against leaking. Moreover, it was found even in the case of the standard-weight fitting that the pipe in the connection ruptured under the stress before the fitting would give way.

Another illustration of the extreme tenacity of the red brass is shown by the fact that it is nearly 50 per cent. more difficult to machine, polish, and buff than is yellow casting, being *prima facie* proof that a metal which will resist the incursion of the machine tool will possess paramount qualities from a wearing standpoint, and possesses the highest resistance to all forms of erosion.

While copper is not ordinarily affected or corroded by such agencies as moisture or acids inducing rust and oxidation, yet tin, zinc, and lead are especially affected by these, and we may therefore say that fittings are susceptible to rust, oxidation, or corrosion in direct ratio with the amount of tin, zinc, and lead which they contain.

Inasmuch as corrosion attacks that portion of any structure which is most delicate, its inroads principally affect the threads and working surface of these fittings, and leaks are more often occasioned by this agency than are usually conceded.

Especial attention is here called to the fact that in testing a fitting for high-pressure gas or air, the hydraulic test is only good as indicating the tensile strength of the fitting and not to indicate tightness, it being found that valves or cocks found tight under the 300 lbs. of water pressure frequently leak when subjected to 40 lbs. of air. This fact seems little known among either manufacturers or engineers, but it will be found, as a rule, that when a

fitting is found tight under a pressure of 40 lbs. it will be tight under any other reasonable pressure, or, generally speaking, up to its safe working capacity or even to the rupture point of the metal.

Globe-valves, Tees, and Elbows.—The reduction of pressure produced by globe-valves is the same as that caused by the following additional lengths of straight pipe, as calculated by the formula:

$$\text{Additional length of pipe} = \frac{114 \times \text{diameter of pipe}}{1 + (3.6 \div \text{diameter})}.$$

Diameter of pipe....	1	1½	2	2½	3	3½	4	5	6 inches
Additional length....	2	4	7	10	13	16	20	28	36 feet
Diameter of pipe....	7	8	10	12	15	18	20	22	24 inches
Additional length....	44	53	70	88	115	143	162	181	200 feet

The reduction of pressure produced by elbows and tees is equal to two-thirds of that caused by globe-valves. The following are the additional lengths of straight pipe to be taken into account for elbows and tees. For globe-valves multiply by $\frac{3}{2}$:

Diameter of pipe....	1	1½	2	2½	3	3½	4	5	6 inches
Additional length....	2	3	5	7	9	11	13	19	24 feet
Diameter of pipe....	7	8	10	12	15	18	20	22	24 inches
Additional length....	30	35	47	59	77	96	108	120	134 feet

These additional lengths of pipe for globe-valves, elbows, and tees must be added in each case to the actual length of straight pipe. Thus a 6-inch pipe 500 feet long, with 1 globe-valve, 2 elbows, and 3 tees, would be equivalent to a straight pipe $500 + 36 + (2 \times 24) + (3 \times 24) = 656$ feet long.

Joints for High-pressure Mains.—All sockets or couplings shall be extra heavy, of the best quality of metal, and have taper threads. Preferably these joints should be tight and free from leakage without the use of "dope," but where some joint compound is necessary litharge and glycerine are best used.

Where flange-joints of any kind are used, the gasket should be made of $\frac{3}{16}$-in. lead wire, the ends of which are soldered together.

Where valves are used upon high-pressure lines or storage-tanks instead of cocks, these too should be of the extra-heavy ammonia type, although even these will be found to give more or less trouble, unless of a first-class quality and carefully selected.

Main-regulators.—Where high-pressure mains are controlled through automatic regulators the equipment should invariably be in duplicate, the regulators being connected into the line in

parallel, and each equal to sustaining the maximum load of the entire line. The regulators should be connected in with proper valves and possess by-passes between their inlets and outlets, all of which connections to be flanged, to expedite ready removal and replacement. All of the above should be surrounded by proper brick or concrete manholes to afford accessibility.

Drips.—All traps, pockets, or depressions in almost every high-pressure line should be dripped after the method of low-pressure practice. This may usually be done by cutting into the line a tee (looking down and whose opening is equal to the diameter of the pipe) into whose run a short section of pipe is connected, which is duly capped and fitted with a small relief-pipe terminating at some convenient place and fitted with a pocket-head pet-cock, which latter acts as a "bleeder." Through an arrangement of this kind the condensation accumulating in the drip can be periodically "blown off." This condensation is usually created by the change of vapor tension due to the varying compression upon the volume of gas in the main, extending from the maximum pressure during peak load hours to possibly atmosphere or merely holder pressure (if the service be a booster or feeder line), or at least considerably reduced during the period of minimum demand.

Anchorage.—All bends and curves in high-pressure mains should be firmly anchored in order to prevent gyration; the straight runs should also be heavily anchored, perhaps about twice as often as the expansion joints (about one every 500 ft.). Expansion joints and lateral branches of all sorts should also be strongly anchored to prevent buckling and thrust. The tendency of a high-pressure main to "writhe" is much greater than is generally known, for, in addition to the initial pulsations caused by the compressor, there is a reflex which creates a powerful "gas-hammer."

Expansion Joints should be placed not less frequently than one every 1000 feet.

Testing High-pressure Mains is done much after the fashion of low-pressure work, with the exception that a portable air-compressor, say 6 H.P., direct-connected to a gasoline-, alcohol-, or vapor-engine, is generally used. An outfit of this kind will also be found extremely convenient for a number of purposes; it can have in its equipment a centrifugal pump and hose connections, which will be found of great convenience in emptying ditches, cesspools, drips, etc., of water, with a saving of time and labor.

Pneumatic Tools.—The compressor may also be fitted with a pneumatic hammer into which cape and diamond-point chisels may be used for cutting pipe; and with calking-tools for driving up joints. These tools should fit the chuck loosely so as to move freely in the workman's hand. The calking done by the pneu-

matic hammer is far superior to that done by hand, being equal throughout, and especially driving home the lead at the bottom of the joint and underneath the pipe, which is usually slighted in handwork. It has the further advantage of time and economy, and in permitting the ordinary laborer to do a better job of calking

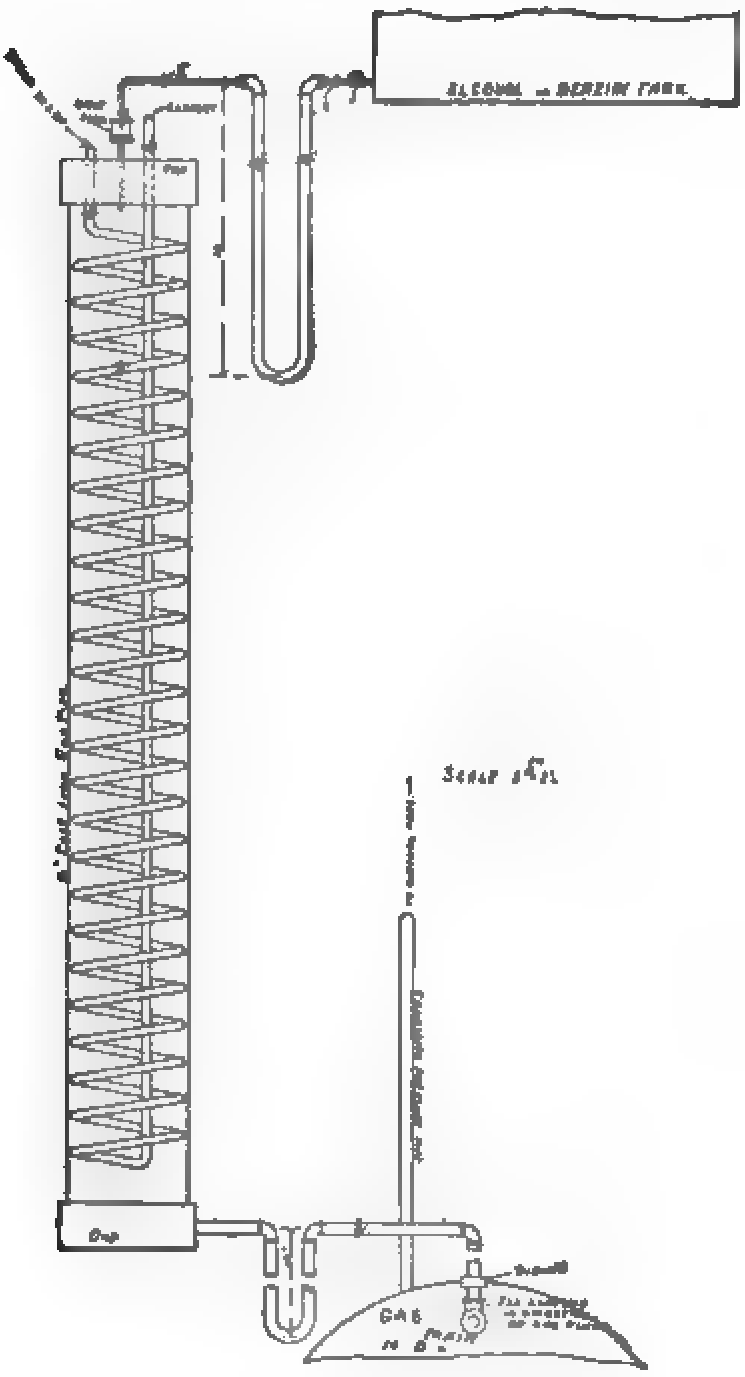


FIG. 36—Naphthalene Removal Vaporizer.

than that usually accomplished by a skilled and expensive workman.

Pipe Deposits.—To remove stoppages in the mains, services, meters, house-pipes, fixtures, and burners, and to clear out naphthalene, tar, and other hard stoppages, the writer has found it

convenient to vaporize wood-alcohol or benzine and inject it into the mains by means of a vaporizer (Fig. 36), a diagram of which is herewith given.

A quantity, say 20 gallons, of alcohol is put into a tank and admitted through a sight-feed into a drum, where it is vaporized by a steam-coil. The inlet of this drum is duly sealed by a pipe-trap in order to prevent the return of the vapor or the exit of the gas into the alcohol-tank. This alcohol vapor, passing out through another trap, is admitted into the mains and carried forward by the gas, experiment showing it to have a travel of at least 3 miles. It instantly dissolves all naphthalene and invariably attacks and makes soluble other similar substances. Ten or 15 gallons per 1,000,000 cu. ft. thus admitted into the mains for a day or so, say twice a year, will be of incalculable value in cleansing the system, especially where Welsbach service is extensively used.

Leaks.—The question of leakage, or a large portion of what is known as "gas unaccounted for," should be a matter of con-

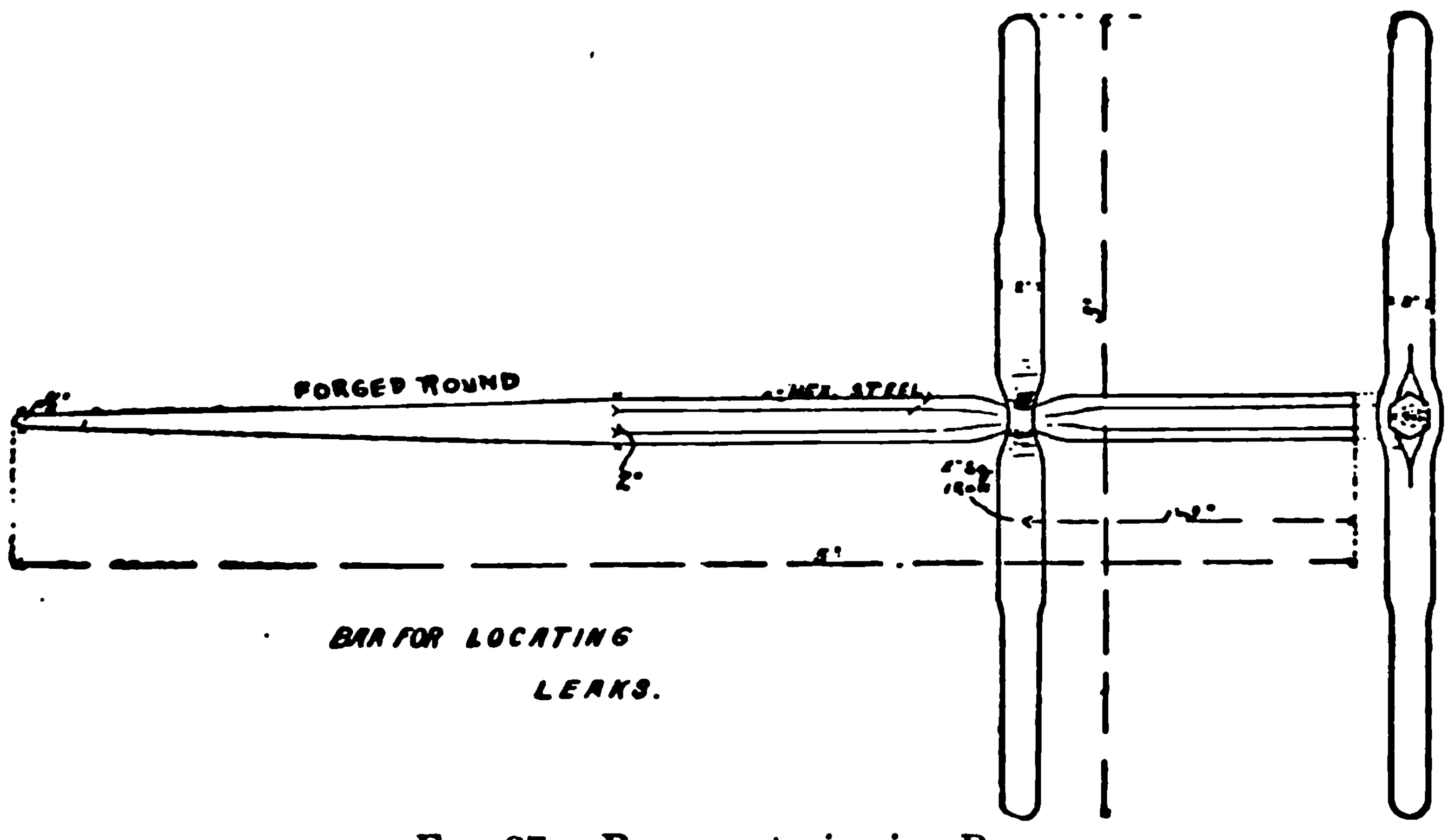


FIG. 37.—Pavement-piercing Bar.

stant attention upon the part of the superintendent. Of course a large portion of this seeming discrepancy is by reason of change of temperature, either during the process of works distribution or after storage, gas varying $\frac{1}{498}$ of its bulk approximately for every degree Fahrenheit over 32° above zero. There is, however, in all systems a certain amount of leakage due to bad joints, which occur either from poor construction, change in temperature, or instability on the part of the ground or foundation where laid.

The entire system of every gas company should be periodically

"barred." An iron bar (Fig. 37) with a loose handle for removing, large at one end to form an anvil for the sledge and tapering at the other, should be driven down at the bell end of a pipe, such joint being first definitely located. Great care should be taken that the bar should not be driven with sufficient force to injure the pipe, and to this end it is better to use a bar with a malleable point than a steel bar, which is apt to cut. The bar then being removed from contact with the bell, leaking gas should be sought in the hole thus made, first by the sense of smell and afterwards by the application of a match.

Test for Leakage.—Under conditions where, by reason of a comparatively odorless gas or for other reasons, it is impracticable to discover leakage by the sense of smell, test may be made by applying at suspected points a paper saturated with a solution of palladous chloride from which metallic palladium is precipitated in the presence of traces of carbon monoxide; the reaction being as follows:

$$PdCl_2 + CO + H_2O = Pd + 2HCl + CO_2.$$

The blackening of the paper indicates the presence of CO gas.

Records.—A measurement should then be taken in the direction of the run of the pipe (equal to one length of the pipe) and the next joint located, when the experiment can be repeated. All leaks discovered should be marked, reported, dug up, and recalked. Where the calking lead drives up too far, a new lead joint should be run and its tightness ascertained by the application of heavy soap-suds.

This sort of work, together with all repair work, can be greatly facilitated by the use of accurate records in the office, recording the location of all pipes, drips, valves, services, etc., indicating the direction of flow, the juncture of feed-line and crosses, etc. In order to bring this information to the office, where a proper record can be made and filed, the writer suggests the use of a card (Fig. 38), which should be supplied to the foreman of main construction, who can fill in thereon, with a rule and pencil, the location of pipe, distance from property line, class of fittings, location of valves, drips, crosses, etc., and the direction of fall. From these cards a map can be made, showing an entire district, which will be found valuable in the regulation of pressure and the addition of extensions, after which the card should be filed for future use.

Service Connections.—It is doubtful whether under any conditions it is good economy to use galvanized pipe for services, inasmuch as nearly all agencies which tend to destroy black iron will also attack the zinc coating of galvanized pipe. Medium-weight steel pipe will be found far better.

It is good practice in connecting a service with the main to tap the latter on top and screw therein a street **T**. The street **L** is then screwed into the street **T** at its side outlet, thereby forming a swing joint. The chief advanta*g*e of this connection is that gas can be cut off by the opening in the **T** from the service while it is being laid, which opening can be also used for examining the

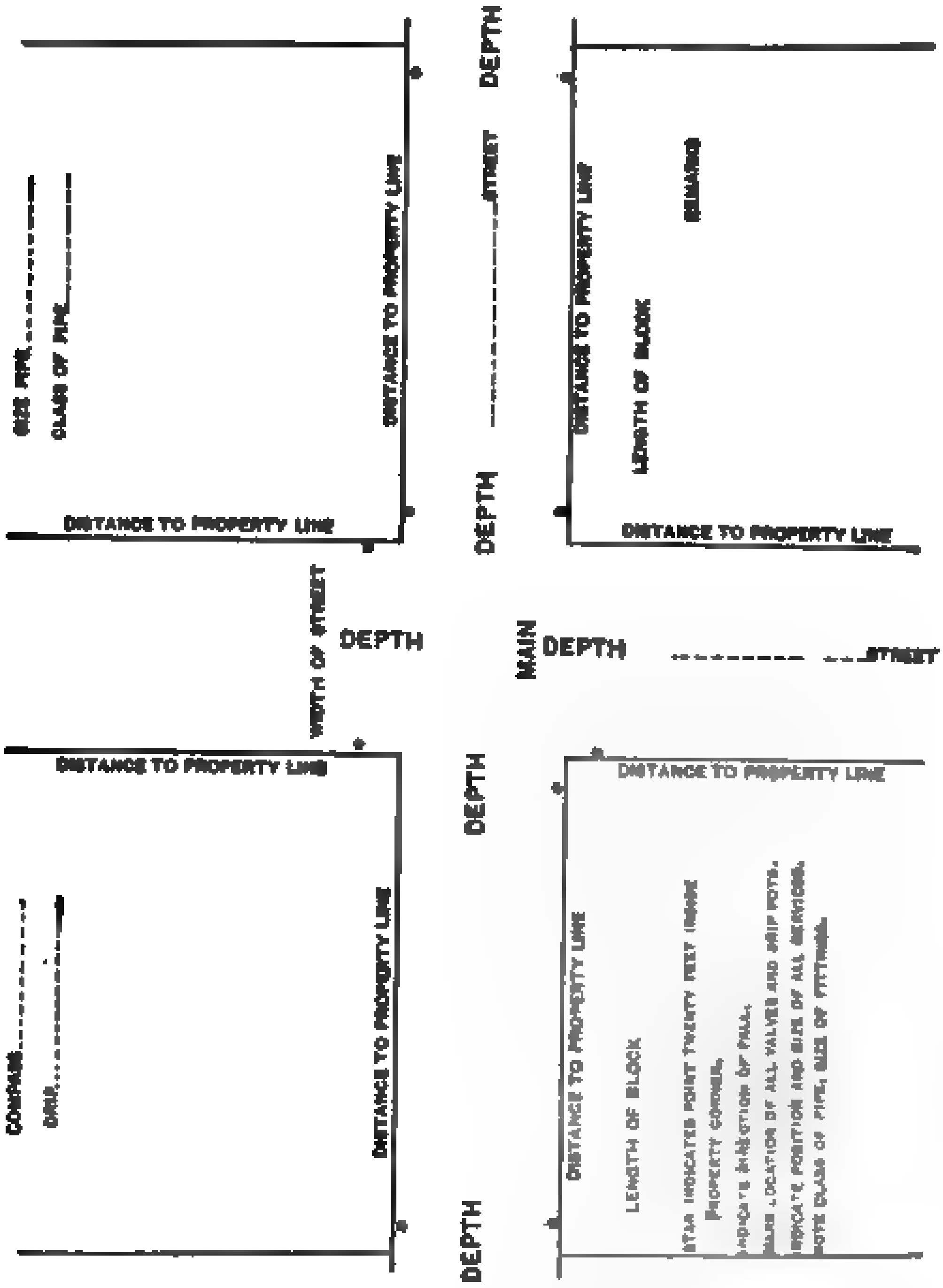


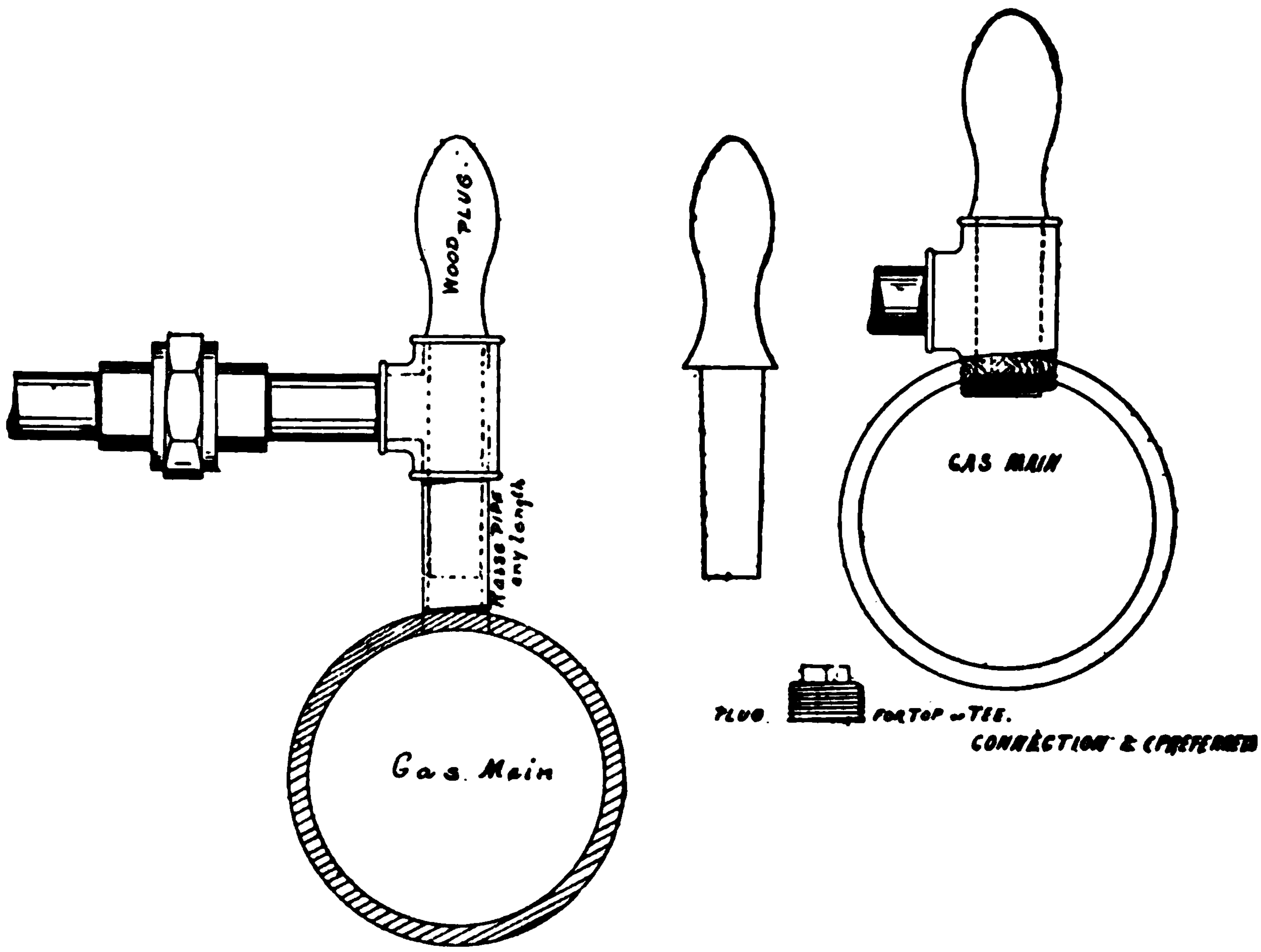
FIG. 38.—Main and Service Chart.

service in case of trouble. It also relieves both pipes from either horizontal or vertical strain in settling or crawling (Fig. 39).

There are two methods of cutting cast-iron pipe, both of which can be recommended. The more convenient, especially for sizes under 12 in., is the Hall cutter, which can be used after the man-

ner of wrought-iron pipe-cutters; otherwise the pipe should be cut around with a diamond-nosed chisel until a ring at least $\frac{1}{16}$ in. deep has been formed, when the pipe may be severed with the aid of a dog-chisel.

In pipes over bridges, contraction and expansion, together with vibration, must be allowed for. Wrought-iron pipe is gen-



CONNECTION I.

FIG. 39.—Plug for T Connection to Prevent Gas Escaping while Laying Service Pipes.

erally used in preference to cast, and at either end expansion joints, or, better still, the Dresser sleeves, are placed. There should be valves on either side of the bridge to control the flow of gas in case of accident. These pipes should be kept thoroughly coated, inasmuch as the sulphur in engine smoke, in the case of railway bridges, is most deleterious in its action.

It is the custom of a number of companies in the United States to base their extension of mains into unoccupied territory upon one prospective consumer to every 100 feet of main. The advantage of this system seems to be demonstrated by the best practice.

All valves in a main system should systematically and con-

sistently be either all right-handed or all left-handed, that is, closing in the direction of the hands of a clock or the reverse. This, more than anything else, prevents confusion and the possibility of having a valve in the system closed without the likelihood of discovery.

One of the great nuisances in gas distribution is the formation of iron carbonyl. It may possibly be the result of unoxidized purifying material, but is more likely the result of gas coming in contact with new iron borings, such as the tapping of a large number of services into a new section of main is apt to produce. It appears generally at the burner tip and may be remedied by the admission of water into either main, services, or purifying-boxes to complete the oxidation.

The general advantages of cast-iron over wrought-iron pipe for gas purposes are: first, its greater ability to resist the corrosion of the soil; secondly, its greater thickness between internal and external diameters, permitting better service connection and abolishing the necessity of additional fittings for such connections, thereby reducing the liability to leakage.

Repairing Breaks. — In case of broken mains a temporary repair can be made by bandaging with cloth between the folds of which are wrapped copious layers of soap, pipe-clay, or, better still, Tucker's cement, portions of which filling having been previously forced into the crack or crevice of the pipe before the application of the bandage. The permanent remedy depends upon the nature of the injury. Should the break run around the circumference and the entire damage be included within a lateral space of 4 or 5 in., a split sleeve may be used. Should, however, the break run lengthwise the pipe, the better practice is to cut out the injured section, replacing it with new pipe, the final joint being made with a solid sleeve which is slipped over the joint.

When a split sleeve is used, the pipe must be first thoroughly cleaned of all dirt and rust, and if it is settled it should be blocked back into proper grade and alignment. A strip of unbleached muslin, wide enough to cover the break, with a margin of 6 or 8 in. on either side, and long enough to circle the pipe twice or more, should be smeared thickly with putty or Tucker's cement, or a mixture of equal parts of white and red lead and linseed-oil, and wrapped tightly around the pipe above the break.

A split sleeve can then be applied so as to cover the break, with a margin of at least 4 in. on either side. The joint between the sleeve and the pipe may be made as follows: A number of pieces of millboard soaked to a pulp in hot water may be forced between the sleeve and the pipe and tightly corked. When this

is dry a lead or cement joint of the regular type, the former preferred, may be made on either end of the sleeve.

When it is necessary to remove altogether a damaged section of pipe, the pipe should be cut at a distance not less than 8 in.

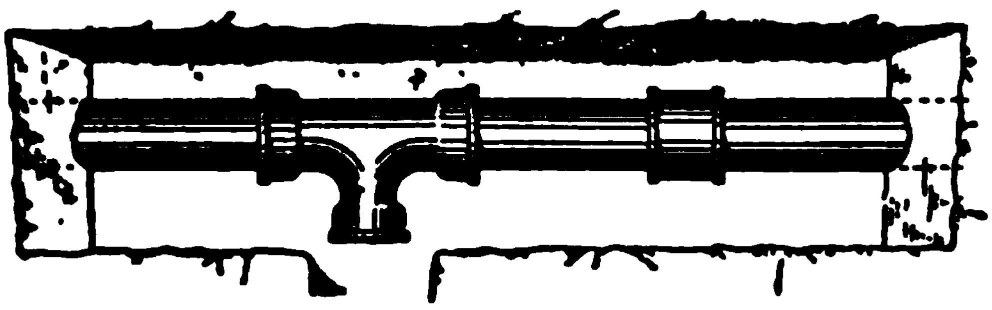


FIG. 40.—Method of "Cutting" in a Fitting (Correct), Using a Solid Sleeve.

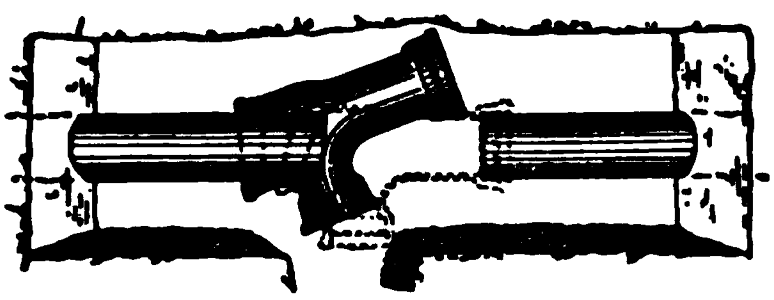


FIG. 41.—Method of "Springing" in a Fitting (to be Avoided) without Use of Sleeve.

prior to appearance of the break or crack; this cut may be made either by the use of regular pipe-cutters, or by cutting around with a diamond-nosed chisel and severing with a dog-chisel. When the new section is installed, aligned, and graded before sliding the sleeve, which in this case should be solid, into place, the spigot ends, which must just meet, should be brought together and wrapped with unbleached muslin, prepared as before described, with the use of the split sleeve. The solid sleeve may then be slid over the bandage and the joint made as before described in the regular manner.

Flour or meal in small sacks has on several occasions been used to choke dangerous fires occurring through leakage in manholes.

Main-stoppers.—In bagging off a main that is likely to be internally coated with naphthalene or rust, the rubber bag should be inserted in a canvas cover in order to protect the rubber surface from the action of the oily deposit. This may be placed by use of a bag fork, which is a simple wire contrivance, with blunt end. Where the main is under considerable pressure, it should be doubly bagged, two separate taps and bags being placed on each gas-head, and as an additional precaution, where the pressure is especially high, a patent gas diaphragm stopper, consisting of a contrivance of canvas and wires, may be placed before the bag in a separate tap. It is well to use bags one size larger

than the diameter of the tap to be plugged. These bags should always be inflated by the use of a small hand bicycle pump, and never by the lungs, as the breath condensation is deleterious to the rubber, to say nothing of the effect upon the workmen of the gas inhaled.

Gas bags after use may be preserved by being inflated with dry air, the necks being corked, instead of tied, with wooden pins or plugs. The bags should then be coated with tallow and stored in a damp place.

Successful efforts have been made to bag off a main with water, extra-strong bags being used.

Repair Work.—Pressure may be shut off and the end of a main plugged temporarily by the use of a large compact ball of cloth or cord, fitting the pipe, to which proper straps have been firmly attached to facilitate ready removal.

COSTS OF INSTALLING MAINS.

Excavation Costs.—The following table, for which the writer is indebted to M. E. Malone, will be of value in estimating labor operations, and constitutes a very fair average of work in handling different kinds of material that the average laborer can handle in a specified time, in cu. ft. per man per hour.

MATERIAL HANDLED PER MAN.

	Cu. Ft. per Man-hour.
Asphalt (3.5-in. and 6-in. concrete)	4.298
Sand and clay	24.700
Clay	19.220
Sand and broken stone	22.000
Loam	35.000
Broken shale	17.330

Cost of Loading and Hauling Cast-iron Pipe.—Much of the following data is from Gillette's Handbook of Cost Data. Three men assisted by a driver averaged 5 lengths of 12-in. pipe loaded from a flat car to a wagon and the pipe was rolled down the plank runway. This same gang would unload a wagon in 6 minutes. As each length of pipe weighed nearly ½ short ton, the wagon load was 2.5 tons. It therefore cost 5 cents per ton to load and 2.5 cents per ton to unload the wagons, wages of men being 15 cents per hour; but this does not include the lost time of two horses during loading and unloading, which is equivalent to about 2 cents per ton. The total fixed cost of loading and unloading was 10 cents per ton, including team time. The hauling costs 12 cents per

ton per mile where 2.5 tons are the load (wages of team and driver 35 cents per hour) and the team returns empty. Good hard level roads are required for so large a load. If the haul is short and this loading gang of 3 men walks along with the wagon, the cost of hauling becomes 25 cents per ton-mile instead of 10 cents.

Pipe should never be shipped in hopper-bottom cars, for the difficulty of unloading adds very much to the cost. I have had a gang of 6 men who unloaded only 75 lengths of 12-in. pipe in 10 hours from a hopper gondola into wagons. Each length weighed 800 lbs., making 30 tons the day's work at 30 cents per ton. This work was by hand, no derrick being available.

Trenches for water-pipes in the northern United States are usually 5 ft. deep from the surface of the street to the axis of the pipe. In the South trenches are only 3 ft. deep. Water-pipe trenches are usually dug not less than 18 to 24 ins. wider than the inside diameter of the pipe; and just before the pipes are laid a gang of men enlarge and deepen the trench for a short space where each pipe joint is to come; this is called digging the "bell-holes." The bell-holes enable the yarners and calkers to make the joints properly. It is usually not necessary to brace the sides of a trench that is only 5 or 6 ft. deep.

Cost of Trenching.—At Corning, N. Y., a trench for a 10-in. water-pipe was excavated 2.5 ft. wide × 5 ft. deep × 1500 ft. long, which equals 600 cu. yds., in 4.5 days by 24 men, or at the rate of 6 cu. yds. per man per 10-hour day, equivalent to 11 cents per running foot or 25 cents per cu. yd. The backfilling was done in three days by 2 men and 1 horse with driver, using a drag scraper and a short length of rope, so that the horse worked on one side of the trench while the two men handled the scraper on the opposite side, pulling the scraper directly across the pile of earth. In this way the backfilling was made at a cost of 1.1 cents per linear foot or 2.5 cents per cu. yd., there being no ramming of the backfill required. This is a remarkably low cost for backfilling and one not ordinarily to be counted upon. The material was a loamy sand and gravel.

At Rochester, N. Y.—With the size of trench and kind of material practically the same results were obtained as above:

One man excavated 8 cu. yds. a day at a cost of 19 cents per cu. yd.; 1 man backfilled 16 cu. yds. a day at a cost of 9 cents per cu. yd. Total cost of excavation and backfill, 28 cents per cu. yd.

Cost of Trenching, Great Falls, Mont.—The Great Falls (Montana) Water Co. excavated 25,500 cu. yds. of earth, 1900 cu. yds. of loose rock, and 1500 cu. yds. of solid rock in trenching

for a 6-in. water-pipe. The work was done by company labor (not by contract), wages being $2.25 for laborers, and the cost was 34 cents per cu. yd. for excavation and 3.5 cents more per cu. yd. for backfilling and tamping. If wages had been $1.50 a day the cost would have been 23 cents per cu. yd. for excavation and 2.5 cents per cu. yd. for backfilling.

Cost of Trenching, Astoria, Oregon.—A. L. Adams states that in trenching for the Astoria (Oregon) Water-works in 1896 the first contractor averaged only 7 to 8 cu. yds. per man per day. Later on another contractor, even in the rainy season, averaged nearly 10 cu. yds. per man per 10-hour day of trenching (including backfilling) at a cost (including foreman) of 17.5 cents per cu. yd., wages being $1.70 a day. The material was yellow clay dug with mattocks and shovels.

Cost of Trenching, Hilburn, N. Y.—W. C. Foster gives the following data on 17,000 ft. of trenching for water-pipe at Hilburn, N. Y. The trench was 4 ft. deep for 4-in. to 8-in. pipe. The digging was hard, the banks being full of cobbles and frequently caved in. The streets were not paved. The cost of trenching and backfilling was 10.1 cents per lin. ft., wages being $1.35 for laborers and $3 for foreman.

Cost of Trenching and Pipe-laying, Providence, R. I. — In *Engineering News*, June 28, 1890, E. B. Weston, Engineer Water Department, Providence, R. I., gives very full records of pipe-laying costs. The tables on page 171 are given by him and are based upon many miles of trench-work.

Wages in all cases above were $1.50 a day for laborers trenching and laying, $3 a day for foreman, $2.25 for calkers, and $2.25 for teams, which probably refers to teams without driver. Carting was in all cases $1 a ton. Allowance for tools (item 4) was made on a basis of 7.25% of items 1 and 2.

Short lengths, 15 to 50 ft., of 6-in. pipe cost 34 cents per foot in easy digging to 45 cents in hard digging for excavation, laying, and backfilling, wages being as above stated.

The trench for a 24-in. pipe 19,416 ft. long and 6.6 ft. deep cost 32 cents per cu. yd. for excavation and backfill with wages at $1.50 a day.

A 48-in. main was laid for $1.65 per ft., including digging, laying, calking, and backfilling.

A 16-in. pipe 374 ft. long passed under two railway tracks, and the cost of trenching, laying, and backfilling was 50 cents per ft.

An 8-in. pipe was laid across a bridge, and the cost of boxing, laying pipe, etc., was $1.32 per ft., while for a 12-in. pipe the cost was $1.50 per ft.

EASY DIGGING, SAND.

Size of Pipe, In.	4	6	8	10	12	16	20
1. Trenching *...	.0422	.0518	.0611	.0707	.0798	.1445	.2088
2. Laying......	.0129	.0162	.0191	.0219	.0249	.0370	.0497
3. Foreman.....	.0130	.0158	.0188	.0216	.0244	.0303	.0360
4. Tools, etc....	.0041	.0050	.0059	.0069	.0078	.0134	.0191
5. Calking......	.0106	.0107	.0108	.0111	.0118	.0159	.0301
6. Lead, 5 cts. lb.	.0224	.0320	.0431	.0553	.0683	.0950	.1203
7. Teams.......	.0070	.0090	.0115	.0136	.0160	.0203	.0216
8. Carting......	.0078	.0149	.0208	.0275	.0346	.0518	.0746
9. Total........	.1200	.1554	.1911	.2286	.2676	.4082	.5602

MEDIUM DIGGING, GRAVEL, ETC.

Size of Pipe, In.	4	6	8	10	12	16	20	24
1. Trenching *...	.0597	.0697	.0790	.0883	.0974	.1700	.2400	.3019
2. Laying......	.0189	.0220	.0249	.0279	.0307	.0440	.0577	.0639
3. Foreman.....	.0180	.0206	.0234	.0265	.0294	.0350	.0373	.0396
4. Tools, etc....	.0056	.0065	.0075	.0084	.0093	.0154	.0214	.0602
5. Calking......	.0106	.0107	.0108	.0111	.0118	.0159	.0301	.0757
6. Lead, 5 cts. lb.	.0224	.0320	.0431	.0533	.0683	.0950	.1203	.1600
7. Teams.......	.0070	.0090	.0115	.0136	.0160	.0203	.0216	.0228
8. Carting......	.0078	.0149	.0208	.0275	.0346	.0518	.0746	.1317
9. Total........	.1500	.1854	.2210	.2586	.2975	.4474	.6030	.8630

HARD DIGGING, HARD OR MOIST CLAY.

Size of Pipe, In.	4	6	8	10	12	16	20
1. Trenching *...	.0860	.0959	.1053	.1147	.1300	.2261	.3264
2. Laying......	.0271	.0303	.0333	.0362	.0411	.0530	.0669
3. Foreman.....	.0260	.0286	.0314	.0343	.0372	.0428	.0452
4. Tools, etc....	.0081	.0090	.0099	.0109	.0118	.0201	.0283
5. Calking......	.0106	.0107	.0108	.0111	.0118	.0159	.0301
6. Lead, 5 cts. lb.	.0224	.0320	.0431	.0553	.0683	.0950	.1203
7. Teams.......	.0070	.0090	.0115	.0136	.0160	.0203	.0216
8. Carting......	.0078	.0149	.0208	.0275	.0346	.0513	.0746
9. Total........	.1950	.2304	.2661	.3036	.3508	.5250	.7134

* Including backfilling. In all cases the depth of the trench was such that the center of the pipe was 4 ft. 8 in. below ground surface.

Trenches were ordinarily 2 ft. wider than the pipe and 5 ft. plus half the diameter of the pipe deep. Such trenches were dug, the pipe laid, and backfilling made at the following rate per laborer engaged:

Diameter Pipe Inches.	Material.	Feet Length per Day.
6	Easy earth	21.0
6	Medium earth	17.2
6	Hard earth	10.3
8	Easy earth.	19.3
12	Medium earth.	13.4
20	Easy earth	9.0
24	Medium earth.	4.4

Earth excavation in trenches where digging is easy cost 20 cents per cu. yd.; rock excavation averages $2 per cu. yd., running as high as $3 per cu. yd., wages being $1.50 per day.

Where long pipe-lines are to be constructed a line of levels should first be run and, the drip of the pipe being taken into account, the entire length should be laid off by the engineer in convenient units of equal volume.

Although the quality of the soil, unforeseen obstacles, etc., will vary to some extent the unit rate of progress, this will serve as a basis for the checking of the progress of work from day to day besides establishing a basis for the computing of future operations.

Careful records should be made of the character of the soil, nature of obstacles, etc., encountered, which should be filed as a portion of the daily data and should be ultimately classified for future reference.

The labor itself should also be handled on the unit basis, the work being so laid out in units and decimals thereof that a check can be kept upon the individual output.

Upon these data (where not hampered by Unionism) the labor may be classified under the respective headings A, B, C, and D, of which B may represent the normal or average and be paid the standard rate of wage, the normal being obtained either from empiric data or the immediate work done. A may constitute a class of labor whose output is in excess of the average or B class, to whom a bonus of from 10 to 20 per cent should be paid, depending upon their marginal efficiency. It must be remembered, however, that in addition to their work *per se* these men constitute the "pace-makers" of the force and should be paid accordingly. Class C will be formed of those falling immediately below the average and should be constantly culled for dismissal, while all those crossing the dead-line between Class C and Class D, or, let us say, showing a deficiency of 15% below the average of Class B, should be discharged from the work at once.

COST OF PIPE AND LAYING PER LINEAR FOOT.

(From Gillette's Handbook of Cost Data.)

Size of Pipe, Inches Diam.	Weight per Length, Lbs.	Weight per Linear Ft., Tons of 2000 lbs.	Cost at $30 per Ton.	Teaming, 30 cts. per Ton-mile, Haul, 2.5 m.	Lead, 5 cts. per lb.	Miscellaneous Expenses.	Labor.	Total Cost.
12 A.	810	0.034	$1.02	$0.025	$0.100	$0.065	$0.45	$1.66
12 E.	1,040	0.043	1.29	0.035	0.100	0.065	0.46	1.95
14 A.	1,010	0.042	1.26	0.030	0.120	0.070	0.46	1.94
14 E.	1,310	0.055	1.65	0.040	0.120	0.070	0.47	2.35
16 A.	1,215	0.051	1.53	0.040	0.130	0.070	0.50	2.27
16 E.	1,610	0.067	2.01	0.050	0.130	0.070	0.51	2.77
18 A.	1,400	0.058	1.74	0.040	0.150	0.080	0.56	2.57
18 E.	1,910	0.080	2.40	0.060	0.150	0.080	0.58	3.27
20 A.	1,610	0.067	2.01	0.050	0.180	0.090	0.61	2.94
20 E.	2,260	0.094	2.82	0.070	0.180	0.090	0.64	3.80
24 A.	2,050	0.085	2.55	0.060	0.200	0.110	0.70	3.62
24 E.	3,000	0.125	3.75	0.090	0.200	0.110	0.73	4.88
30 A.	2,860	0.119	3.27	0.090	0.250	0.130	0.78	4.52
30 E.	4,340	0.181	5.43	0.135	0.250	0.135	0.83	8.17
36 A.	3,800	0.158	4.74	0.120	0.300	0.140	0.88	6.18
36 E.	5,900	0.246	7.08	0.185	0.300	0.145	0.93	8.64
42 A.	4,920	0.205	6.15	0.155	0.350	0.175	1.02	7.85
42 E.	7,720	0.322	9.66	0.240	0.350	0.180	1.12	11.55
48 A.	6,130	0.256	7.68	0.190	0.400	0.240	1.47	9.98
48 E.	9,740	0.407	12.21	0.305	0.400	0.245	1.57	15.73
54 A.	7,510	0.312	9.36	0.235	0.450	0.275	1.66	11.98
54 E.	12,400	0.516	15.48	0.390	0.450	0.280	1.76	18.36
60 A.	8,900	0.370	11.10	0.275	0.500	0.325	1.96	14.41
60 E.	15,100	0.628	18.84	0.470	0.500	0.330	2.12	23.27

A = light-weight pipe. E = heavy-weight pipe.

APPROXIMATE COST OF LAYING WATER-PIPE.

(Another estimate of this kind is compiled by the Glamorgan Pipe and Foundry Co. from actual experience under varying conditions.)

Diam. of pipe, inches	4	6	8	10	12	16	20	24	30	36	42	48
Weight pipe per 12-ft length	213.000	364.00	538.000	739 00	949.000	1496 000	2128.0	2735 00	3930 00	5096 00	7000.00	8700.00
Weight pipe per foot lbs	18 000	30 00	45.000	62.00	79.000	125.000	178.0	228 00	328.00	425 00	583.00	725 00
Weight yarn per joint, lbs	0 190	0.36	0 500	0.60	0.750	1.000	1.2	1.50	1.80	2 16	2.50	3.00
Weight yarn per foot, lbs	0.017	0 03	0.042	0.05	0 063	0 084	0 1	0.13	0.15	0 18	0.21	0.25
Weight lead per joint, lbs	8.000	12 00	15.000	20 00	22.000	28.000	35.0	42.00	53.00	63.00	84.00	96.00
Weight lead per foot lbs	0.660	1.00	1.300	1.66	1.83	2.33	3.0	3.50	4.41	5 25	7.00	8.00
Cost pipe per ft at $30 net ton	0.270	0 45	0.68	0.93	1.19	1.88	2.67	3 42	4.92	6.38	8.75	10.88
Cost yarn per ft at 7 cts lb.	.0012	.0021	.003	.0035	.0044	.0059	.007	.0091	.0105	.0126	.0147	.0175
Cost lead per ft at 5 cts. lb.	.033	.05	.065	.083	.0915	.1165	.15	.175	.2205	.2625	.35	.40
Cost cartage per ft at 75 cts. net ton	.007	.011	.018	.023	.03	.047	.067	.088	.12	.15	.23	.25
Cost trenching and refilling 4-ft cover	.056	.065	.11	.12	.15	.23	.32	.46	.54	.60	.85	1.00
Cost pipe-laying, calking, and cutting	.015	.02	.025	.028	.03	.07	.12	.20	.25	.30	.40	.50
Total cost for av. work per ft.	0.3822	0.5981	0 90	1.18	1.49	2.34	3.33	4.35	6.06	7.70	10.59	13.04
Additional for shoring per ft. if needed	0.04	0.05	0 08	0.11	0.12	0.15	0.20	0.25	0.30	0.40	0.45	0.50
Cost setting hydrants 1 l'gth pipe	2.50	3.00	3.50									
Cost setting valves and boxes	1.25	1.50	1.75	2.00	2.50	2.80	3.50					

Rock requiring blasting will cost on average $3 per cubic yard. Replacing Telford surface will cost 30 cents per square yard.

Cost of Water-pipe Laid at Alliance, O.—L. L. Tribus gives the following costs of work done in 1894, the material being loam and clay excavated to such a depth that 4 ft. of earth would be left on top of each class of pipe after backfilling.

MATERIAL USED.

Size of pipe, ins.	4	6	8	10	12
Weight of pipe, lbs. per ft.	19	30½	44	62	79
Lbs. specials per ft.	0.4	0.76	1.1	1.55	1.9
Lbs. lead per ft.	0.4	0.66	1.0	1.25	1.5
Lbs. yarn per ft.	0.02	0.025	0.05	0.08	0.1
Total length in ft.	2890	9760	1860	3320	2930

COST PER LINEAR FOOT LAID.

Size of pipe, ins.	4	6	8	10	12
Pipe	$0.2360	$0.3780	$0.5350	$0.7470	$0.9400
Specials and valves	.0120	.0189	.0268	.0374	.0470
Hauling	.0056	.0078	.0011	.0145	.0190
Lead	.0020	.0330	.0500	.0630	.0750
Yarn	.0014	.0018	.0035	.0056	.0070
Trenching	.1240	.1210	.1287	.1480	.1902
Pipe-laying	.0370	.0346	.0313	.0542	.0463
Total	$0.4360	$0.5951	$0.7764	$1.0697	$1.3245

This work was done by laborers and men employed by the water company and does not include cost of superintendence. The 4-ft. cover over the pipe was in some cases exceeded. The digging was comparatively easy with little ground-water to bother. Mr. Tribus informs me that the wages paid were: Laborers, $1.25; pipe-haulers, $1.50; and calkers, $2.25, per 10-hour day.

Cost of Water-pipe Laid in a Southern City.—In *Engineering News*, March 30, 1893, C. D. Barstow gives very complete tables of cost of shallow trenching and pipe-laying in a Southern city, where negro laborers were used. From the data given by him I have compiled the following table of cost.

For the most part the trenches were 15 in. wide at bottom and 20 in. at top, and 3 ft. deep. Some trenching was done using a team on a drag scraper, 20 in. wide; then the trench was made 3 ft. at top. After a rain, however, the scrapers could not be used to advantage. In using a plow for loosening the earth, several feet of chain are fastened to the end of the plow-beam, and one or more men ride the beam; in this way plowing may be done in a trench 4 ft. deep, one horse walking on one side and one on the other side of the trench. A blacksmith was kept busy sharpening

about 60 picks a day. There was a night-watchman. The pipe was distributed by contract at 34 cents per ton.

TABLE OF COST OF TRENCHING AND PIPELAYING IN THE SOUTH.

Wages per 10-hour day for negro laborers, $1.25; for calkers, $1.75; for white foreman, $3.00; for teams, $3.25; for horse ridden by boy, $1.50.

Job.	A.	B.	C.	D.	E.	F.
Pipe, ins.	10[1]	....	6	8	10	8[8]
Length, ft.	11,000	6,000	6,215	11,352	2,639	21,856
Width trench, ft.	2	....	....	....	....	....
Depth trench, ft.	3.5	3	3	3	3	3
Material.	[2]	[4]	....	....	....	[9]
Number laborers digging.	33	30	40	31	45	46
Number teams plowing.	....	....	....	3½	5	2½
Team time, cts. per ft.	....	....	....	0.80	0.62	0.60
Labor, digging, cts. per ft.	6.66	2.74	5.19	2.68	2.12	4.00
Foreman, digging, cts. ft.	0.50	0.23	0.31	0.21	0.12	0.20
Labor, pipe-laying, cts. ft.	2.04	....	0.63	0.77	0.94	1.12
Foreman, pipe-laying, cts. ft.	0.39	....	0.17	0.21	0.18	0.24
Bell-hole digging, cts. ft.	2.70	....	0.77	0.98	0.93	1.16
Bell-hole digging, foreman, cts. per ft.	0.27	....	0.16	0.21	0.18	0.18
Calking, cts. per ft.	1.30	....	0.52	0.64	0.63	0.75
Backfill and tamping:						
Labor, cts. per ft.	4.32[3]	1.00[5]	1.01[6]	2.09	1.42[7]	0.95[9]
Foreman,* cts. per ft.	0.36	0.22	0.22	0.32	0.18	0.18
Team,* cts. per ft.	....	....	0.36	....	....	0.41
Horse ridden by boy, cts. per ft.	....	....	0.07	....	0.09	....
Total cost, cts. per ft.	18.54	4.19	9.45	8.91	7.41	9.79

The lead and yarn consumed per foot of pipe (length 12 ft.) was:

1.3 lbs. of lead and 0.04 lb. of hemp. for 12-in pipe;
0.96 lb. " " " 0.04 " " " " 10-in. "
0.95 " " " " 0.03 " " " " 8-in. "
0.66 " " " " 0.02 " " " " 6-in. "

* Backfill with drag scraper.

[1] Trenching in an old street, 1200 ft. in very muddy ground. Two rainy spells in 18 days of work. Then 10-in. pipe was laid for 3440 ft.; then 4038 ft. of 12-in. pipe were laid for 1½ cts. per foot less than it cost for the 10-in. pipe; then 3270 ft. of 8-in. pipe were laid for 2½ cts. per foot less than it cost for the 10-in.

[2] Cemented clay and gravel requiring hard picking. Frequent rains.

[3] The backfilling and tamping done most thoroughly, a stretch of 2550 ft. requiring 3 days for 30 men.

[4] Sand and loam, bottom land, very easy digging.

[5] Very little shoveling and no tamping; 11 men in 7 days backfilled 9620 ft. of trench.

[6] Drag scrapers used to backfill; boy riding horses to tamp, gang 22 men, 3 teams, 1 boy, and horse, 2 days on 5447 ft.

[7] Backfilled 1670 ft. in one day by 19 men, using one boy and horse on tamping.

[8] Half the pipe was 8 in. at cost here given, half was 6 in. costing less for laying.

[9] Ground wet and often muddy. Backfilling 11,433 ft. done by 12 men and 2 teams on scrapers in 7 days; no tamping.

Some 6000 ft. of 2-in. wrought-iron service pipe were laid in 2 ft. deep trenches at a trenching cost of 1.9 cts., laying 0.24 cts., backfilling 0.71 cts., without tamping.

		Men, Days.	Cents per Linear Foot.
Removing brick and concrete	Foreman	0.5	2.61
	Laborers	7.0	
Excavating trench	Foreman	0.5	6.30
	Laborers	18.0	
Backfilling and tamping well	Foreman	1.0	4.09
	Laborers	10.6	
Labor relaying concrete		7.8	2.61
" " bricks		4.5	4.59
Professional brick-pavers		4.0	
" brick-helpers		2.0	
Hauling away 23 loads surplus earth			1.23
15 cu. yds. sand cushion			4.02
1700 new bricks			6.92
18 bbls. cement to relay concrete			6.20
Total			38.58

Cost of Taking Up an Old Pipe-line.—E. E. Fitzpatrick furnishes the following data relative to taking up more than 3 miles of pipe-line in Greenburg, Kansas. There were 10,200 ft. of 4-in. pipe, 4310 ft. of 6-in., 2050 ft. of 8-in., and 890 ft. of 10-in. After digging the trenches the 8-in. and 10-in. pipes were raised a little and fires built under the joints until the pipe expanded; then the pipes were unjointed by working them up and down with a three-leg derrick. The 4-in. and 6-in. pipes were raised bodily in long sections onto the bank, heated a little, and unjointed by means of jack-screws and clamps. The time required to do all the trenching, backfilling, and unjointing was equivalent to the work of one man for 425 days; and, assuming wages at $1.50 a day, the cost was only $3\frac{3}{4}$ cts. per foot of pipe.

Cost of Subaqueous Pipe-laying.—A line of 12-in. water-pipe was laid in a trench dredged across a river 500 ft. wide, as follows: The water in the river averaged 4 ft. deep, and the trench was dug 6 ft. deep, making a depth of 10 ft. from water surface to bottom of the trench. To lower the pipe into the trench A-frame bents were built of 4×6-in. timber, the legs of the bents straddling the trench, and each pipe was supported by an iron rod passing through a hole bored in the horizontal member of the A frame. These rods were about 12 ft. long, $\frac{5}{8}$ in. diameter, and threaded their full length. Each rod was provided with a hook at its lower end to hook into an iron ring around the pipe. The pipe was ordinary cast-iron pipe, and was leaded and calked while suspended from the A frames. Then it was the intention to lower the 500 ft. of

pipe all at one time by putting a man with a monkey-wrench at each rod, to give the nut on the rod a turn at a given signal from a whistle. There were 43 bents, 12 ft. apart, and it was decided that a force of 10 men could lower the pipe satisfactorily by giving a few turns of the nuts on 10 rods, then moving to the next 10 rods, and so on. Through carelessness or mischief, some of the men gave more turns to the nuts than the signals called for. This threw the weight of several pipes upon one or more rods, and broke one of them at the hook, which was the weak spot. Immediately all the other rods broke in rapid succession, dropping the pipe-line into the river. The pipe settled to the bottom without breaking in two anywhere, and only one joint showed any leakage when inspected immediately after the accident. This joint was calked by a man who dived down repeatedly, and struck a few blows each time. However, the diver was sent to examine every joint, and inspection showed the pipe-line to be intact from end to end. The cost of building the A frames, placing and calking the pipe-line, was as follows:

10 men, 3 days, at $1.75	$52.50
1 foreman, 3 days, at $3.00	9.00
10 men, 1 day at work lowering pipe, at $1.75	17.50
1 foreman, 1 day at work lowering pipe, at $3.00	3.00
1 diver, 1 day inspecting line	25.00
Traveling expenses of diver	15.00
Total for 516 ft. of pipe	$122.00

The above does not include the cost of the iron rods, nor the timber used in the bents, nor the building of a small raft from which to erect the A-frame bents.

From this experience I believe it would be safe to dispense with the threaded iron rods for lowering such a line of pipe. The pipe could be held just above the water surface by small manila ropes until calked. Then upon cutting one or two of the ropes the rest would break and allow the pipe to settle into the water. As the pipe-line is quite buoyant when filled with air it settles down gently upon the bottom of the trench. In case a break should occur in the line, threaded rods could be made and the pipe raised and repairs made at but slightly greater expense than would have been incurred had rods been used in the first place. When pipe is lowered as above described, one flexible pipe-joint is usually provided at each end of the pipe-line.

Cost of Laying Pipe Across the Susquehanna.—James P. Herdic gives the following data relating to laying 10-in. iron pipe

across the Susquehanna River at Montoursville, Pa., a distance of 600 ft., the average depth of water being 13 ft. A $\frac{7}{8}$-in. manila rope was first stretched across the river, to act as a ferry-line for the scows. The scows were loaded with pipe. The crew of eight men and foreman were engaged 1 day in this preliminary work, and then laid the 600 ft. of pipe-line in the next $2\frac{1}{2}$ days. One ball-and-socket joint was used to every six ordinary joints. The pipe-line was lowered between two scows by means of chain pulleys suspended from a heavy sawhorse that spanned the gap between the two boats. The pipe was laid in a gentle curve, bowed up-stream, so as to form an arch to resist the stronger currents.

In an instance on the Susquehanna River, also described in Gillette's excellent Handbook, where the current was sufficiently swift to swamp a scow if handled by the above method, the scow was held in the current at an angle to its flow, nose up-stream, ropes being anchored from bow and stern to nearest shore in such a manner that the force of the current kept the ropes taut. The pipe lay across the middle of the scow, which was moved out from under the line as fast as each joint was made up. Six common joints to each ball and socket were used.

Cost of Laying 6-in. Pipe Under Water.—Still another Gillette record is as follows: About 5100 ft. of 6-in. pipe were laid from the New Jersey shore to Ellis Island, the depth of water being from 10 to 17 ft. A trench was dug 5 ft. deep by 10 ft. wide in the mud, using a clam-shell bucket. Heavy pipe, weighing 800 lbs. per length, with Ward flexible joints was used. Two scows 26×80 ft. each were fastened together at a distance of 6 ft., and were provided with two skids of 10×10 timbers 55 ft. long, leading down between the scows to the bottom of the trench. The skids could be lowered in rough weather. Two lengths of pipe were placed by a derrick upon the skids at one time, these being made up, and the scows were warped ahead 24 ft. This work, with a force of ten laborers, two calkers, and one diver, required just one month.

Cost of Laying Pipe Across the Willamette River.—The *Engineering Record* of Sept. 19 and 26, 1897, records the laying of a 32-in. pipe across the Willamette River, Oregon: Two scows and an inclined cradle were used. The force was sixteen men and one diver. They laid 80 ft. of pipe per day in a trench 23 ft. below the surface of the water.

Designating Crosses.—In ordering reducing tees, it becomes necessary to name the run and outlet. Fig. I illustrates diagrammatically the run and outlet and shows the tee reducing on the outlet. Such a tee is read $2\times1\frac{1}{2}$ ins. The run is read first. In

[illegible]

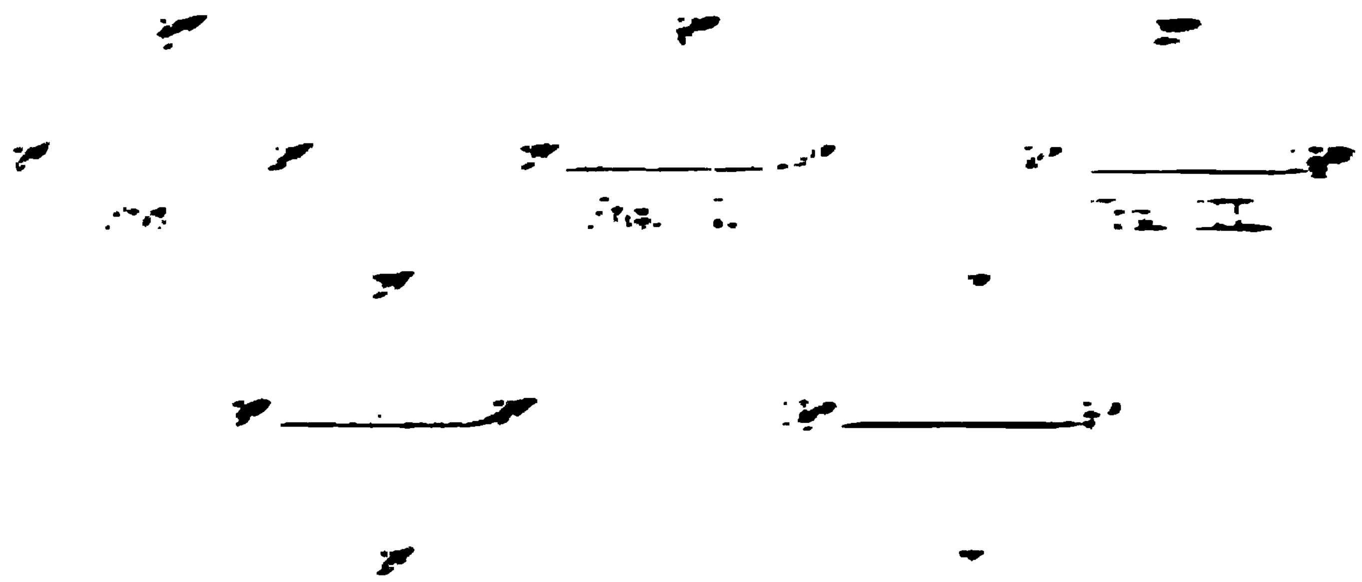


Fig. V

[illegible] A very important rule [illegible] as follows: The outlets of a cross are [illegible] of the same size and indicated by the last figures. By [illegible] it will be seen that the outlets are [illegible] ins., while [illegible] it follows that a reducing cross must reduce on the run. [illegible] shows the outlets are [illegible] ins., while the run is [illegible] It should be remembered that crosses are read on the [illegible] and when reducing on the run three figures are to be mentioned, when reducing on the outlets two figures are to be mentioned.

Lead-wool Joints. The use of this material in the jointing of cast-iron pipe will be found under many conditions most convenient and satisfactory. The enormous strength of the joints produced and their freedom from leakage, due to their homogeneous structure, make them especially adaptable for high-pressure service.

These joints are also excellent for submarine work, inasmuch as they may be made up under water, and more especially because of the tremendous flexibility rendered the pipe-line by their use; in this connection experiments have shown a deflection in a bell-and-spigot joint of 10° 12′ without leakage under a pressure of 2000 lbs., affording an excellent arrangement where any pipe-line is subject to vibrations, strains, or deflections. The joints are practically unaffected by the bending or settling of the pipe-line.

Lead wool is lead cut in fine fibers. These fibers are put into the joint in the same way as yarn. The lead is being calked from the yarn up, not only at the outside. The result is an absolutely tight, perfect joint that will never leak.

The lead being calked in cold, obviates the loss in fit due to the shrinkage of the casting in the contraction of cooling. The following general claims are made for it:

No melting of lead; no waste of material; calking may be done in wet grounds or on rainy days; joints may be made up and calked under water.

AMOUNT OF LEAD WOOL NECESSARY FOR VARIOUS JOINTS.

Size of joint	3″	4″	6″	8″	10″	12″	16″	20″	24″	30″	36″
Pounds of cast lead used	5	6	9	13	17	20	30	40	65	90	103
Pounds of lead wool used	..	..	6	10	12	14	20	28	40	65	65

Owing to the fact that every ounce of lead that goes into the joint is calked by using lead wool, whereas the cast lead joint can be calked to the depth of about half an inch only, we advise the putting in of lead wool to the depth of

1¼ inch on all joints up to 6 inches.
1½ " " " " " " 12 "
1¾ " " " " " " 36 "

Concerning the cost of lead wool, which is about 12 cents per pound in ton lots, which would increase the cost considerably if the same quantity of lead wool were used. It will be seen from the figures that this is not necessary and that the amount of lead wool necessary is a good deal less than that of cast lead.

The strength of a lead-wool joint is immensely superior to any other made. The Mannesman Seamless Tube Co. have successfully tested lead-wool joints on a pressure of over 4000 lbs. It is a safe statement, therefore, that a lead-wool joint will hold a much greater pressure than cast-iron pipe.

Directions for Using Lead Wool.

No. 1 and 2 calking tools should be made with a dull triangular point instead of a square.

Have one leg of the edge made slightly shorter than the other, and use the shorter end against the spigot. This will drive the lead well up into the crease.

The trimming tools remain square.

In calking joints with lead wool the most important point is to hammer in each layer of fibers as hard and tight as possible.

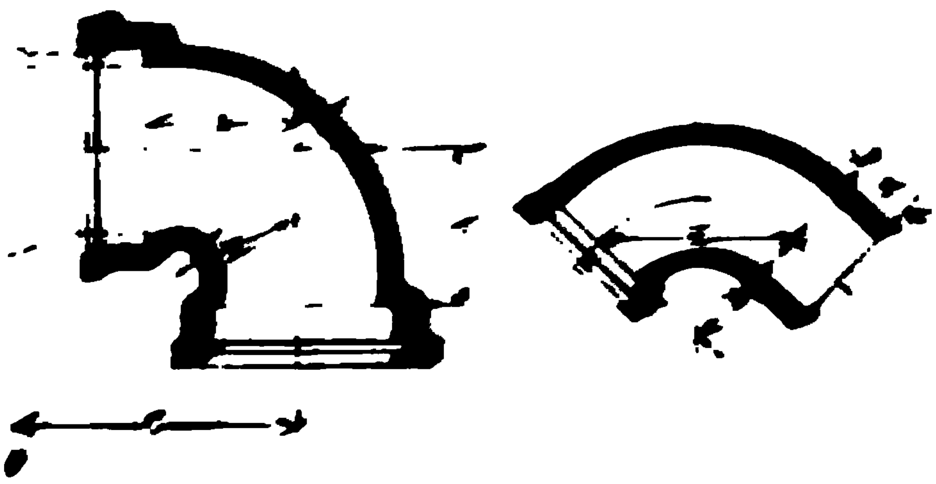
Unless the lead wool be calked tightly from the bottom up, it will not hold better than a lead joint.

Tar oakum is preferable to dry oakum, because the lead wool will better adhere to it.

The strands of lead wool are put in one at a time; each strand should be calked separately.

The lead wool need not extend beyond the crease. This means a great saving of lead. Up to the crease the joint is calked with yarn.

MAIN SPECIALS.

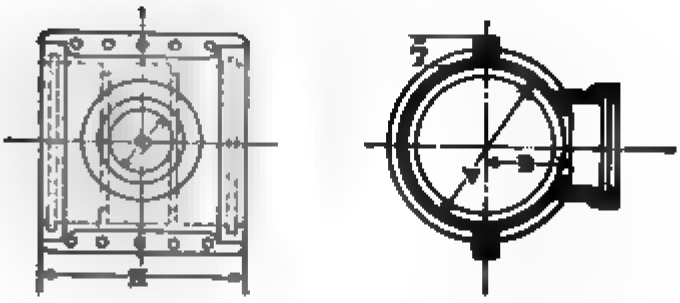


QUARTER BENDS.

Size	Thickness of Metal	A	C	B
4	.40	4.50	15.00	3.00
6	.43	6.25	16.50	4.50
8	.46	8.00	18.00	6.00
10	.49	9.75	19.50	7.50
12	.54	11.25	21.00	9.00
16	.60	14.50	24.00	12.00
20	.67	17.75	27.00	15.00
24	.76	21.00	30.00	18.00

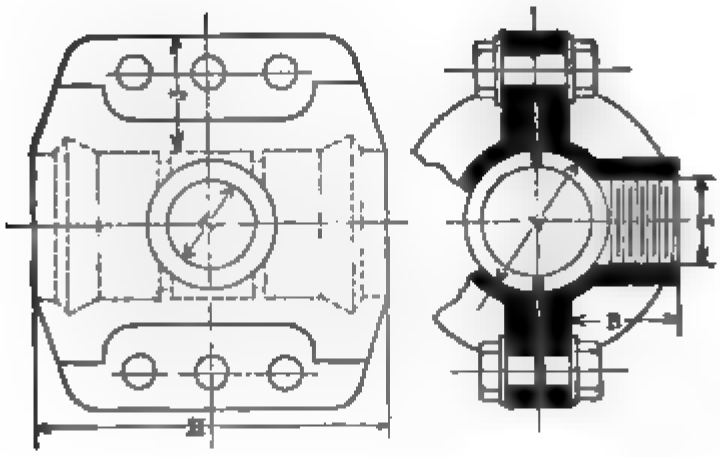
LARGE HUB AND SPIGOT QUARTER BENDS.

Size	Thickness of Metal	R	S	K
24	.76	30	12	42.4
30	.88	36	12	50.9
36	.99	48	12	67.9
42	1.10	60	12	84.8
48	1.26	66	12	93.32



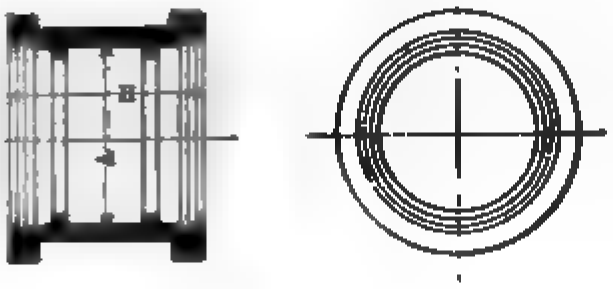
HUB SLEEVE.

Size.	Thickness.	*A*	*B*	*H*	*J*	*S*
10× 4	.49	12.10	6.55	15	3.00	4.00
10× 5	.49	12.10	6.55	18	3.00	6.00
12× 4	.54	14.20	7.64	15	3.00	4.00
12× 6	.54	14.20	7.64	18	3.00	6.00
16× 6	.60	18.30	9.80	18	3.75	[illegible]
16× 8	.60	18.30	9.80	18	3.75	8.00
20× 6	.67	22.59	11.97	18	3.75	6.80
20× 8	.67	22.59	11.97	18	3.75	8.00
20×10	.67	22.59	11 97	18	3.75	10.00



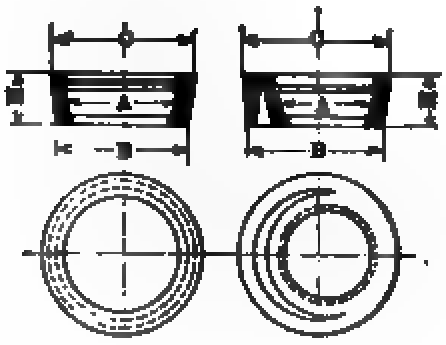
SERVICE SLEEVE.

Size.	Thickness of Metal.	*A*	*B*	*H*	*J*	*T*
2	.38	3.38	2.35	8	2.75	1.25
2	.38	3.38	2.35	8	2.75	1.50
3	.38	4.80	3.40	12	2.75	1.25
3	.38	4.80	3.40	12	2.75	1.50
4	[illegible]	5.80	3.85	12	2.75	2.00
6	.43	7.90	5.27	12	2.75	3 00
8	.46	10.05	6.37	12	3.00	3 00



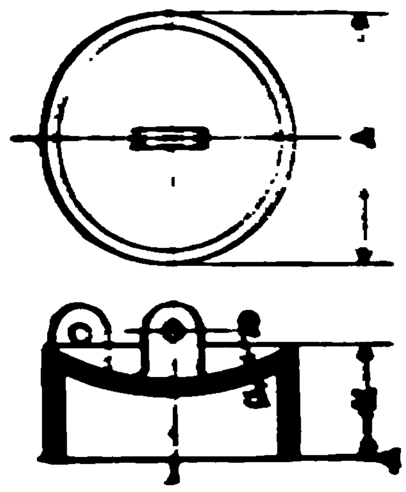
SOLID SLEEVE.

Size.	Thickness of Metal.	A	H
2	.38	3.38	8
3	.38	4.80	[illegible]
4	.40	[illegible]	12
6	.43	7.90	12
8	.46	10.05	15
10	.49	12.10	15
12	.54	14.20	15
[illegible]	.60	18.30	18
20	.67	22 59	18
24	.76	26.77	18
30	.88	32.99	18
36	.99	39.21	18
42	1.10	45.45	18
48	1.26	51.75	18



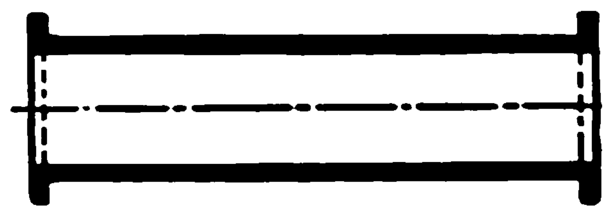
BUSHINGS.

Size.	A	B	C	H
6× 3	4.60	6 65	6.90	4.5
6× 4	5.80	6.65	6.90	4.5
8× 4	5.80	[illegible]	9.05	4.5
8× 6	7.90	8.80	9.05	4.5
10× 6	7.90	10.85	11.10	4.5
10× 8	10.05	10.85	11.10	4.5
12× 6	7.90	12.95	13.20	5.0
12× 8	10 05	12.95	13.20	5.0
12×10	12.10	12.95	13 20	5.0



PLUGS.

Size.	A	G	H	Q
3	3.80	.40	5.25	4.0
4	4.80	.40	5.25	4.0
6	6.90	.43	5.25	6.0
8	9.05	.46	5.25	8.0
10	11.10	.49	5.25	10.0
12	13.20	.54	6.00	12.0
16	17.20	.60	6.00	22.0
20	21.34	.67	6.00	36.0
24	25.52	.76	6.50	60.0
30	31.74	.88	6.50	78.0
36	37.96	.99	6.50	90.0
42	44.20	1.10	6.50	120.0
48	50.50	1.26	6.50	150.0



FLANGED PIPES.

Size.	Diameter, Flange.	Thickness, Flange.	Diameter, Bolt Circular.	Number of Bolts.	Size of Bolts.	Thickness, Pipe.
4	9.0	.72	7.125	4	.625	.40
6	11.0	.77	9.125	4	.625	.43
8	13.5	.81	11.125.	8	.625	.46
10	16.0	.86	13.75	8	.625	.49
12	19.0	.93	15.75	8	.625	.54
16	22.5	1.00	20.00	12	.750	.60
20	27.0	1.00	24.50	16	.750	.67
24	31.0	1.125	28.50	16	.750	.76
30	37.5	1.25	35.00	20	.875	.88
36	44.0	1.375	41.25	24	.875	.99
42	50.75	1.56	47.75	28	1.00	1.10
48	57.00	1.75	54.00	32	1.00	1.26

[illegible]

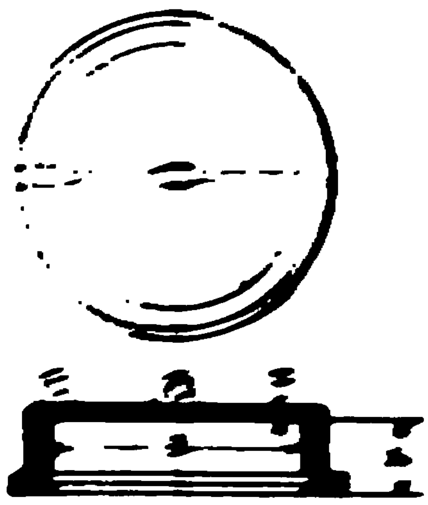
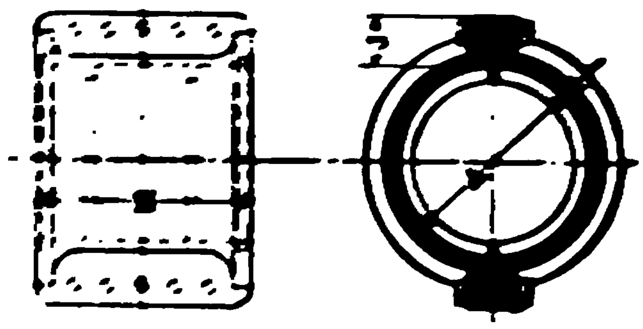


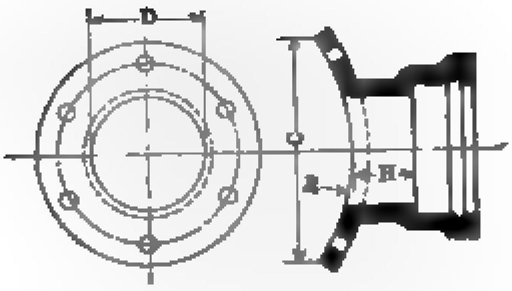
Fig. 29

Size	D	F	G
3	4.80	4.00	.40
4	5.80	4.00	.40
6	7.90	4.00	.43
8	10.05	4.00	.46
10	12.10	4.00	.49
12	14.20	4.50	.54
16	18.30	4.50	.60
20	22.50	4.50	.67
24	26.77	5.00	.76
30	32.90	5.00	.88
36	36.21	5.00	.99
42	45.45	5.00	1.10
48	51.75	5.00	1.26



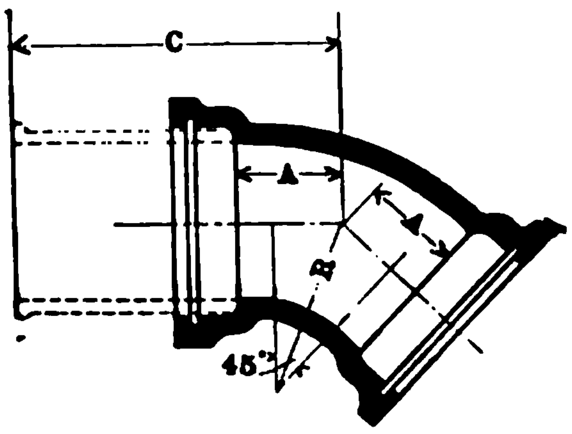
SPLIT SLEEVES.

Size	Thickness, C	A	H	J	Number of Bolts.	Diameter, Bolts.
2	.38	3.38	8.0	2.75	4	.75
3	.38	4.80	12.0	2.75	6	.75
4	.40	5.80	12.0	2.75	6	.75
6	.43	7.90	12.0	2.75	6	.75
8	.46	10.05	15.0	3.00	8	.75
10	.49	12.10	15.0	3.00	8	.75
12	.54	14.20	15.0	3.00	8	.75
16	.60	18.30	18.0	3.75	10	.875
20	.67	22.50	18.0	3.75	10	.875
24	.76	26.77	18.0	3.75	10	.875
30	.88	32.90	18.0	3.75	10	.875
36	.99	39.21	18.0	4.50	10	1.00
42	1.10	45.45	18.0	4.50	10	1.00
48	1.26	51.75	18.0	4.50	10	1.00



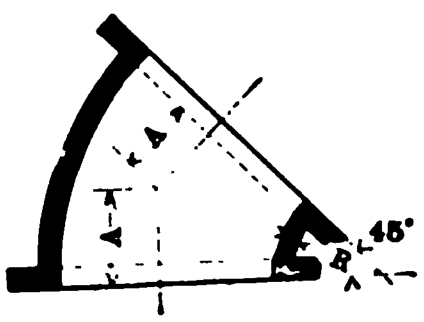
HAT FLANGE.

Size.	Thickness of Metal.	*D*	*E*	*H*	*C*
24×6	.43	6	13.0	4	13.50
24×8	.46	8	13.0	4	15.50
24×10	.49	10	13.0	4	17.50
24×12	.54	12	13.0	4	19.50
30×6	.43	6	16.0	4	13 50
30×8	.46	8	16.0	4	15.50
30×10	.49	10	16.0	4	17.50
30×12	.54	12	16.0	4	19.50
36×6	.43	6	19.25	4	13.50
36×8	.46	8	19.25	4	15.50
36×10	.49	10	19 25	4	17 50
36×12	.54	12	19.25	4	19.50
42×6	.43	6	22 37	4	13 50
42×8	.46	8	22.37	4	15.50
42×10	.49	10	22 37	4	17 50
42×12	.54	12	22.37	4	19.50
48×6	.43	6	25 5	4	13 50
48×8	.46	8	25 5	4	15.50
48×10	.49	10	25.5	4	17 50
48×12	.54	12	25.5	4	19 50



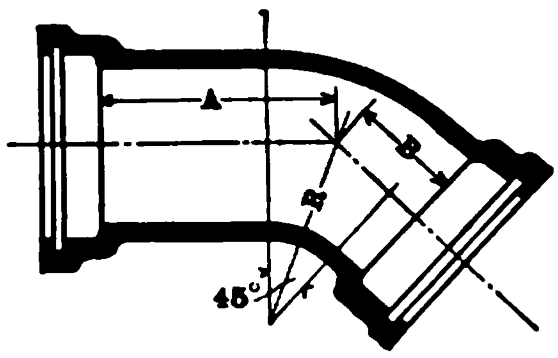
ONE-EIGHTH BEND.

Size.	Thickness of Metal.	*A*	*C*	*R*
4	.40	3.16	20.5	4
6	.43	4.23	21.5	6
8	.46	5.31	22.25	8
10	.49	6.39	23.00	10
12	.54	7.22	24.00	12
16	.60	9.12	25.00	16
20	.67	11.03	27.25	20
24	.76	12.94	29.00	24
30	.88	15.67	31.50	30



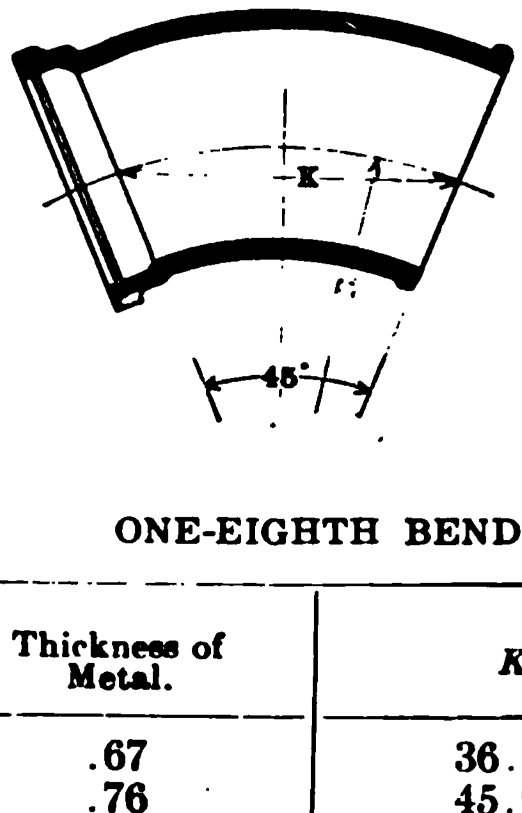
ONE-EIGHTH BEND.

Size.	Thickness of Metal.	*A*	*R*	Diameter, Flange.	Thickness, Flange.
4	.40	3.42	2	9	.72
6	.43	4.23	3	11	.77
8	.46	5.63	3	13.5	.81
10	.49	5.44	4	16	.86
12	.54	5.82	4	19	.93
16	.60	6.62	4	22.5	1.00
20	.67	8.82	5	27	1.00
24	.76	9.59	5	31	1.125
30	.88	11.76	5	37.5	1.250
36	.99	14.65	5.5	44	1.375
42	1.10	15.83	5.5	50.75	1.560
48	1.26	16.97	5.5	57	1.750



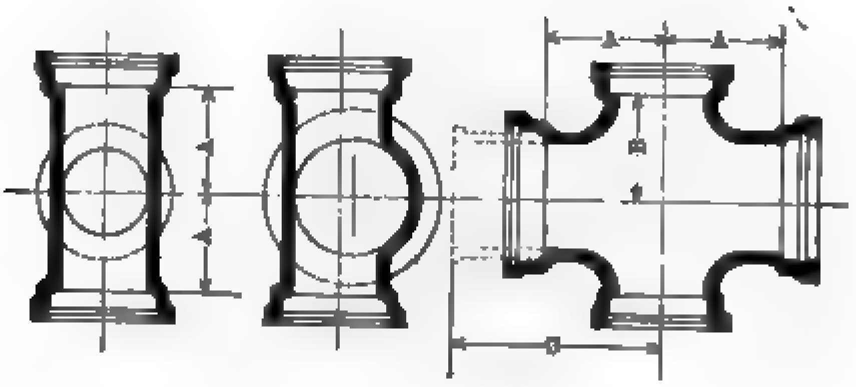
ONE-EIGHTH BEND.

Size.	Thickness of Metal.	*A*	*B*	*R*
4	.40	13.65	3.15	4
6	.43	14.48	4.23	6
8	.46	15.31	5.31	8
10	.49	16.14	6.39	10
12	.54	16.97	7.22	12



ONE-EIGHTH BEND.

Size.	Thickness of Metal.	*K*	*R*
20	.67	36.70	48
24	.76	45.90	60
30	.88	45.90	60
36	.99	68.90	90
42	1.10	68.90	90
48	1.26	68.90	90

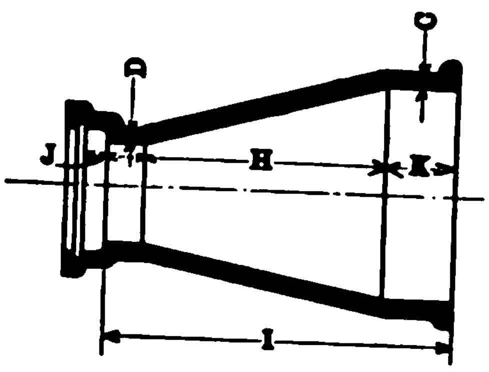


BELLS.

[illegible]	Thickness of Metal.	Distance *A*	Distance *B*	Distance *C*	Diam.	Depth.	Ext. Diam.
4× 4	.40	[illegible]	8	20	5.8	4 0	8.4
6× 4	.43	8	[illegible]	20	7.9	4.0	10.7
6× 4	.40	8	[illegible]	20			
8× 8	.46	10	10	22	10.05	4.0	13.05
8× 6	.43	10	10	22			
8× 4	.40	10	10	22			
10×10	.49	12	12	24	12.10	4.0	15.10
10× 8	.46	12	[illegible]	24			
10× 6	.43	12	12	24			
10× 4	.40	12	11	24			
12×12	54	14	14	26	14.2	4.5	17.4
12×10	.49	14	14	26			
12× 8	.46	14	13	26			
12× 6	[illegible]	14	13	26			
12× 4	.40	14	13	[illegible]			
16×16	.60	17	17	29	18.3	4.5	21.9
16×12	.54	17	17	29			
16×10	.49	17	16	29			
16× 8	.46	17	15.5	29			
16× 6	.43	17	15 5	29			
20×20	.67	19	19	31	22.59	4.5	26.6
20×16	.60	19	19	[illegible]			
20×12	.54	19	17	[illegible]			
20×10	49	19	17	31			
20× 8	.46	19	16	31			
24×24	.76	21	21	[illegible]	26.77	5.00	31.0
24×20	.67	21	21	33			
24×16	[illegible]	21	21	33			
24×12	.54	21	20	33			
24×10	49	21	19	33			

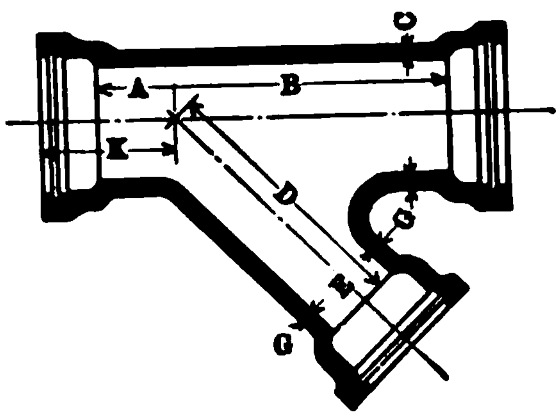
BELLS—*Continued.*

Size.	Thickness of Metal.	Distance *A*	Distance *B*	Distance *C*	Diam.	Depth.	Ext. Diam.
30×30	.88	26	26	41	32.99	5.00	37.6
30×24	.76	23	24	36			
30×20	.67	21	24	34			
30×16	.60	19	24	29			
30×12	.54	15	23	27			
36×36	.99	29	29	44	39.21	5.00	44.21
36×30	.88	26	27	41			
36×24	.76	23	27	36			
36×20	.67	21	27	34			
36×16	.60	19	26	29			
42×42	1.10	32	32	47	45.45	5.00	51.05
42×36	.99	29	30	44			
42×30	.88	26	30	41			
42×24	.76	23	30	36			
42×20	.67	21	30	34			
48×48	1.26	35	35	50	51.75	5.00	57.75
48×42	1.10	32	33	48			
48×36	.99	29	33	44			
48×30	.88	26	33	41			
48×24	.76	23	33	36			



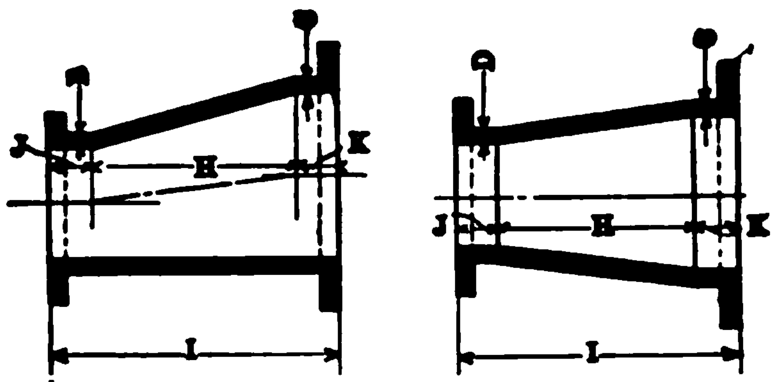
REDUCERS.

Size.	Thickness *C*	Thickness *D*	*H*	*J*	*K*	*I*
14× 6	.57	.46	20	4.0	8	32
14× 4	.57	.40	20	4.0	8	32
18×10	.64	.49	20	4.0	8	32
18× 8	.64	.46	20	4.0	8	32
24×12	.76	.54	26	3.5	8	37.5
30×24	.88	.76	26	3.0	8	37
30×20	.88	.67	26	3.5	8	37.5
30×16	.88	.60	26	3.5	8	37.5
36×30	.99	.88	32	3.0	8	43
42×36	1.10	.99	32	3.0	8	43
48×42	1.26	1.10	32	3.0	8	43
54×48	1.35	1.26	32	3.0	8	43



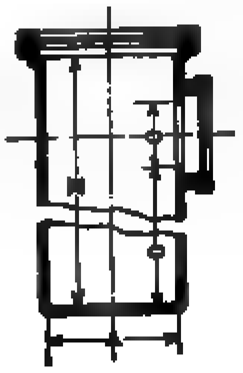
DIMENSIONS.

Size.	Thickness C	Thickness G	E	A	B	D	K
4×4	.40	.40	4	3.16	11.15	11.15	7.16
6×6	.43	.43	6	4.25	15.50	15.50	8.25
6×4	.43	.40	4	4.25	15.50	15.25	8.25
8×8	.46	.46	8	5.31	19.30	19.30	9.31
8×6	.46	.43	6	5.31	19.30	19.05	9.31
8×4	.46	.40	4	5.31	19.30	18.80	9.31
10×10	.49	.49	10	6.75	22.75	22.75	10.75
10×8	.49	.46	8	6.75	22.75	22.50	10.75
10×6	.49	.43	6	6.75	22.75	22.25	10.75
10×4	.49	.40	4	6.75	22.75	22.00	10.75
12×12	.54	.54	12	7.25	26.75	26.75	11.75
12×10	.54	.49	10	7.25	26.75	26.75	11.75
12×8	.54	.46	8	7.25	26.75	26.50	11.75
12×6	.54	.43	6	7.25	26.75	26.25	11.75
12×4	.54	.40	4	7.25	26.75	26.00	11.75
16×16	.60	.60	16	9.12	33.13	33.13	13.62
20×20	.67	.67	20	11.03	38.53	38.53	15.53
24×24	.76	.76	24	13.00	43.00	43.00	18.00
30×30	.88	.88	30	13.75	52.50	52.50	18.75
36×36	.99	.99	36	18.37	60.38	60.38	23.37
42×42	1.10	1.10	42	22.00	70.00	70.00	27.00
48×48	1.26	1.26	48	25.00	80.00	80.00	30.00



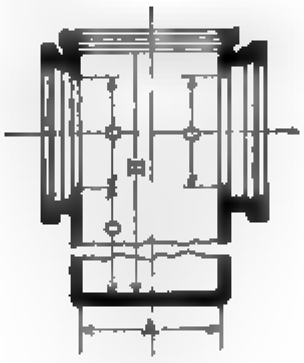
REDUCERS.

Size.	Thickness C	Thickness D	H	J	K	I
6×4	.43	.40	7	2.5	2.5	12.0
8×6	.46	.43	7	2.5	2.5	12.0
8×4	.46	.40	15	2.5	2.5	20.0
10×8	.49	.46	7	2.5	2.5	12.0
10×6	.49	.43	15	2.5	2.5	20.0
10×4	.49	.40	23	2.5	2.5	28.0
12×10	.54	.49	7	3.0	2.5	12.5
12×8	.54	.46	15	3.0	2.5	20.5
12×6	.54	.43	23	3.0	2.5	28.5
16×12	.60	.54	15	2.5	2.5	20.0
16×10	.60	.49	24	3.0	2.5	29.5
16×8	.60	.46	32	3.0	2.5	37.5
20×16	.67	.60	16	2.5	2.5	21.0
20×12	.67	.54	32	2.5	2.5	37.0
20×10	.67	.49	40	3.0	2.5	45.5
24×20	.76	.67	14.5	3.5	3.0	21.0
24×16	.76	.60	30.5	3.5	3.0	37.0
30×24	.88	.76	24.0	3.0	3.0	30.0
30×20	.88	.67	39.0	3.5	3.0	45.5
36×30	.99	.88	24.0	3.0	3.0	30.0
36×24	.99	.76	48.0	3.0	3.0	54.0
42×36	1.10	.99	24.0	3.0	3.0	30.0
42×30	1.10	.88	48.0	3.0	3.0	54.0
48×42	1.26	1.10	24.0	3.0	3.0	30.0
48×36	1.26	.99	48.0	3.0	3.0	54.0



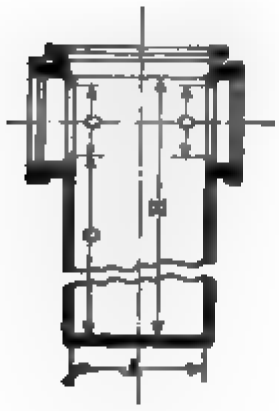
HOLDER DRIPS.

Size.	Thickness of Metal.	*A*	*O*	*H*	*C*
4	.57	14	49.00	54	4
6	.57	14	47.00	54	6
8	.64	[illegible]	45.00	54	8
10	.64	[illegible]	43.00	54	10
[illegible]	.76	24	46.81	60	12
16	.88	30	54.75	72	16
20	.88	30	50.56	72	20
24	.88	30	46.38	72	24
30	.99	36	51.38	84	30
36	1.10	42	45.38	84	36
42	1.26	48	45.38	90	[illegible]
48	1.35	54	39 25	90	48



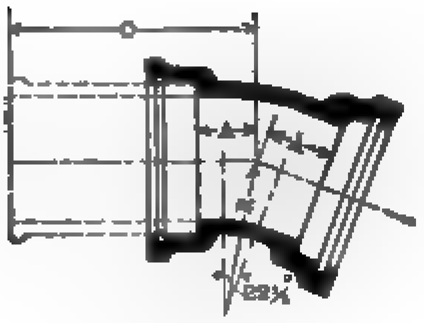
YARD DRIPS.

Size.	Thickness of Metal.	*A*	*O*	*H*	*C*
[illegible]	.57	[illegible]	49.00	[illegible]	4
6	.57	14	47.00	54	6
8	.64	18	45.00	54	8
10	.64	18	43.00	54	10
12	.76	24	46 81	60	12
16	.88	30	54.75	72	[illegible]
20	.88	[illegible]	50.56	72	20
24	.88	30	46.38	72	24
30	[illegible]	36	51.38	84	30
36	1.10	42	45.38	[illegible]	36
42	1.26	48	45.38	90	42
48	1.35	54	39.25	90	48



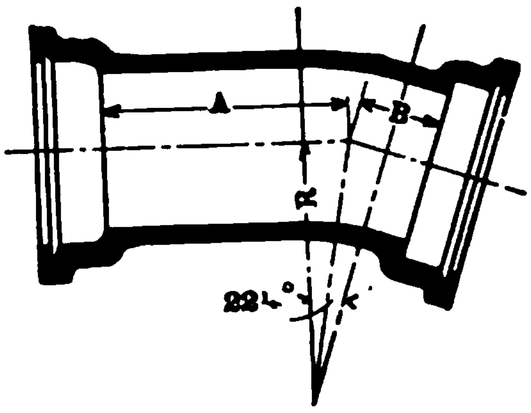
LINE DRIPS.

Size.	Thickness of Metal.	A	O	H	U
4	.54	12	13.00	18	4
6	.54	12	21.00	28	6
8	.54	12	[illegible]	[illegible]	8
10	.60	16	25.00	36	10
12	.60	16	26.81	40	12
16	.67	20	26.75	44	16
20	.76	24	26.56	48	20
24	[illegible]	30	26.38	52	[illegible]
30	.99	36	25.38	58	30
36	1.10	42	25.38	64	36
42	1.25	48	25.38	70	42
48	1.35	54	25.25	76	48



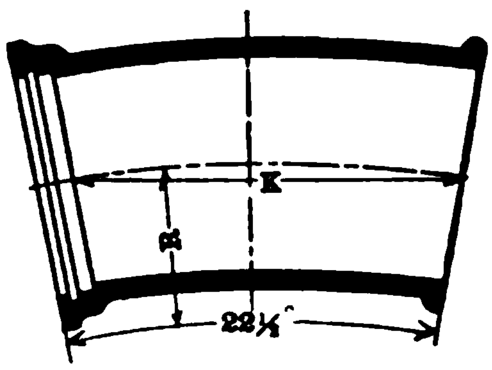
ONE-SIXTEENTH BEND.

Size.	Thickness.	A	C	R
4	.40	2.67	20.25	6
6	.43	3.50	20.75	9
8	.46	4.34	21.25	12
10	.49	5.17	22.00	15
12	.54	5.76	22.50	18
16	.60	7.18	23.75	24
20	.67	[illegible]	24.75	30
24	.76	10.02	25.00	36
30	.83	12.02	27.75	45



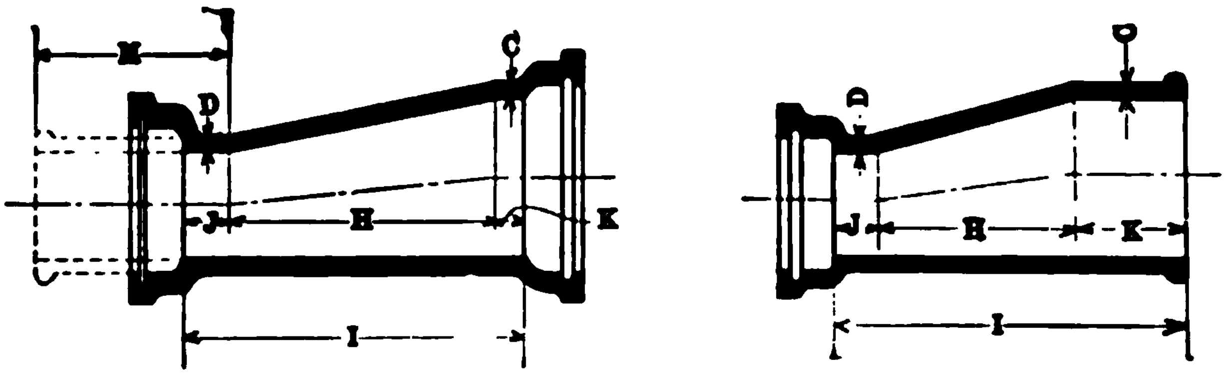
ONE-SIXTEENTH BEND.

Size.	Thickness.	*A*	*B*	*R*
4	.40	14.70	2.69	6
6	.43	15.53	3.53	9
8	.46	16.38	4.38	12
10	.49	17.25	5.22	15
12	.54	17.81	5.81	18



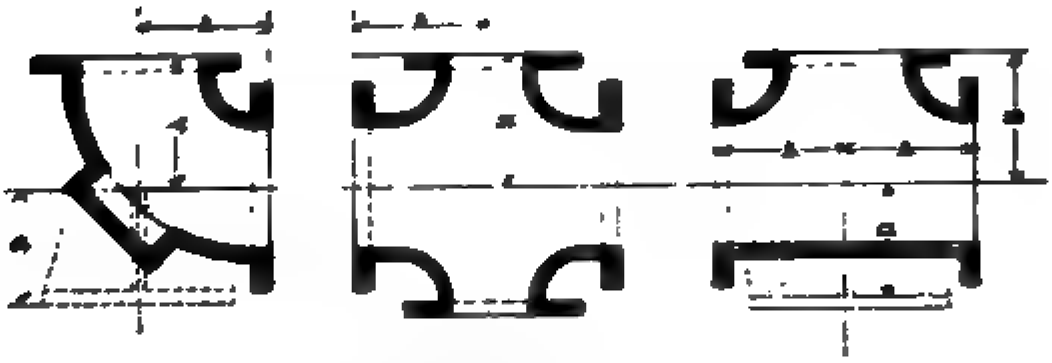
ONE-SIXTEENTH BEND.

Size.	Thickness.	*K*	*R*
20	.67	37.50	96
24	.76	46.80	120
30	.88	46.80	120
36	.99	70.20	180
42	1.10	70.20	180
48	1.26	70.20	180



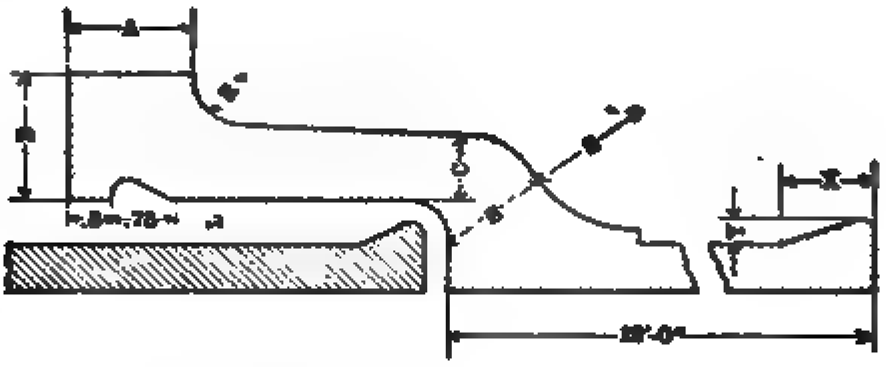
REDUCERS.

Size.	Thickness C	Thickness D	*H*	*J*	*K*	*I*	*M*	*K*	*I*
4× 3	.40	.40	7.0	2.5	2.5	12.0	6.5	6.5	16.0
6× 4	.43	.40	7.0	2.5	2.5	12.0	6.5	6.5	16.0
6× 3	.43	.40	12.0	2.5	2.5	17.0	6.5	6.5	21.0
8× 6	.46	.43	7.0	2.5	2.5	12.0	6.5	6.5	16.0
8× 4	.46	.40	15.0	2.5	2.5	20.0	6.5	6.5	24.0
10× 8	.49	.46	7.0	2.5	2.5	12.0	6.5	6.5	16.0
10× 6	.49	.43	15.0	2.5	2.5	20.0	6.5	6.5	24.0
10× 4	.49	.40	23.0	2.5	2.5	28.0	6.5	6.5	32.0
12×10	.54	.49	7.0	3.0	2.5	12.5	7.0	7.0	17.0
12× 8	.54	.46	15.0	3.0	2.5	20.5	7.0	7.0	25.0
12× 6	.54	.43	23.0	3.0	2.5	28.5	7.0	7.0	33.0
16×12	.60	.54	15.0	2.5	2.5	20.0	7.0	7.0	24.5
16×10	.60	.49	24.0	3.0	2.5	29.5	7.0	7.0	34.0
16× 8	.60	.46	32.0	3.0	2.5	37.5	7.0	7.0	42.0
20×16	.67	.60	16.0	2.5	2.5	21.0	7.0	7.0	25.5
20×12	.67	.54	32.0	2.5	2.5	37.0	7.0	7.0	41.5
20×10	.67	.49	40.0	3.0	2.5	45.5	7.0	7.0	50.0
24×20	.76	.67	14.5	3.5	3.0	21.0	8.0	8.0	26.0
24×16	.76	.60	30.5	3.5	3.0	37.0	8.0	8.0	42.0
30×24	.88	.76	24.0	3.0	3.0	30.0	8.0	8.0	35.0
30×20	.88	.67	39.0	3.5	3.0	45.5	8.0	8.0	50.5
36×30	.99	.88	24.0	3.0	3.0	30.0	8.0	8.0	35.0
36×24	.99	.76	48.0	3.0	3.0	54.0	8.0	8.0	59.0
42×36	1.10	.99	24.0	3.0	3.0	30.0	8.0	8.0	35.0
42×30	1.10	.88	48.0	3.0	3.0	54.0	8.0	8.0	59.0
48×42	1.26	1.10	24.0	3.0	3.0	30.0	8.0	8.0	35.0
48×36	1.26	.99	48.0	3.0	3.0	54.0	8.0	8.0	59.0



FLANGES.

Size.	Thickness of Metal.	Distance A	Distance B	Distance D	Outside Diam.	Finished Thickness.	Diam. Bolt Cir.	No. of Holes.	Size Hole.	a	Bolts.
4 × 4	40	6	6	7	9	72	7 125	4	[illegible]	2	[illegible]×2[illegible]
6 × 6	43	8	8	8	11	.77	9 125	4	[illegible]	3	[illegible]×2[illegible]
6 × 4	43–40	8	8	8							
8 × 8	46	10	[illegible]	9 25	13 5	.81	11 125	8	[illegible]	[illegible]	[illegible]×2[illegible]
8 × 6	46–43	10	10								
10 × 10	49	11	11	10 50	16	86	13 75	8	[illegible]	[illegible]	[illegible]×2[illegible]
10 × 8	49–46	11	11								
10 × 6	49–43	11	11								
12 × 12	54	12	12	11 0	19	93	15 75	8	[illegible]	4	[illegible]×2[illegible]
12 × 10	54–49	12	12								
12 × 8	54–46	12	12								
16 × 16	60	14	14	15 25	22 5	1 0	20 0	12	[illegible]	4	[illegible]×3
16 × 12	6–54	14	14								
16 × 10	6–49	14	14								
20 × 20	67	18	18	16 75	27	1.0	24 5	16	[illegible]	5	[illegible]×3
20 × 16	67 6	18	18								
20 × 12	67–54	18	18								
24 × 24	76	20	20	18 75	31	1.125	28.5	16	[illegible]	5	[illegible]×4
24 × 20	76–67	20	20								
24 × 16	76–60	20	20								
30 × 30	88	24	24	22	37 5	1.25	35.0	20	1	5	[illegible]×4
30 × 24	88–76	24	24								
30 × 20	88–67	24	24								
36 × 36	99	29	29	25 5	44	1.375	41 25	24	1	5.5	[illegible]×4
36 × 30	99–88	29	29								
36 × 24	99–76	29	29								
42 × 42	1 10	32	32	29	50 75	1.56	47.75	28	1[illegible]	5.5	1×4
42 × 36	1 1–99	32	32								
42 × 30	1 1–88	32	32								
48 × 48	1 26	35	35	33	57	1 75	54.0	32	1[illegible]	5 5	1×4
48 × 42	1 26–1.1	35	35								
48 × 36	1.26–99	35	35								



STANDARD STRAIGHT PIPE.

Size.	Thickness.	Ext. Diam.	Diam., Socket.	Depth, Socket.	*A*	*B*	*C*	*L*	Weight, Foot.	Weight, Length.
4	.40	4.80	5.80	4.00	1.50	1.30	.65	0.50	19.0	228
6	.43	6.90	7.90	4.00	1.50	1.40	.70	0.50	30.0	360
8	.46	9.05	10.05	4.00	1.50	1.50	.75	0.50	42.0	504
10	.49	11.10	12.10	4.00	1 50	1.50	.75	0.50	55.8	670
12	.54	13.20	14.20	4.50	1.50	1.60	.80	0.50	72.5	870
16	.60	17.20	18.30	4.50	1.75	1.80	.90	.55	108.3	1300
20	.67	21.34	22.59	4.50	1.75	2.00	1.00	.625	150.0	1800
24	.76	25.52	26.77	5.00	2.00	2.10	1.05	.625	204.2	2450
30	.88	31.74	32.99	5.00	2.00	2.30	1.15	.625	291.7	3500
36	.99	17.96	39.21	5.00	2.00	2.50	1.25	.625	391.7	4700
42	1.10	44.20	45.45	5.00	2.00	2 80	1.40	.625	512.5	6150
48	1.26	50.50	51.75	5.00	2.00	3.00	1.50	.625	666.7	8000

CHAPTER XIV.

SERVICES.

Sizes.—Services for an ordinary dwelling within 40 ft. of a street-main should never be smaller than 1 in.; but it is better practice to run services not smaller than 1¼-in. pipe. The very small increase in cost of service is vastly offset by the saving in efficiency and attention required to maintain it in proper condition, for, aside from its actual capacity for transmitting gas, a small amount of water, naphthalene, or other deposit which would hardly be noticed in a 1¼-in. pipe would seriously affect the flow of gas through a ¾-in. pipe. For large buildings, an estimate of its consumption capacity should be made, and a calculation made from that as to the size of pipe suitable, the calculation being made either by consulting a table or working out the problem by the regular formula for the flow of gases.

When service-cocks are used at the curb, they should be inspected at least once a year, to see that they are in good working order and that the stop-boxes are clean, and the cocks easily accessible. All services should have these curb-boxes, and where such have been omitted they should be cut in, as they are of vital importance in case of fire and other discontinuance of service.

Tapping.—Leaks in piping are most readily located by the introduction into the pipe of essence of peppermint, wintergreen, ether, or pennyroyal with an air-pump. This essence is disseminated by air pressure through the pipe system. The general locality of the leak being indicated by the escaping odor, which may be more immediately localized by the use of heavy soap-suds put on with a camel's-hair brush, the escaping air being indicated by numerous fine bubbles.

Generally in making the tap it should be made in the upper side of the main, using a street **L**, or better still a street **T**, with a plug for making the connections, the connections being thoroughly white- or red-leaded.

It should be borne in mind not to tap too large a service directly

into too small a main. The largest service permissible for tapping direct into a main is as follows:

In a 3-in. main,	a	1-in.	service-tap.
" " 4-in. "	"	1¼-in.	"
" " 6-in. "	"	1½-in.	"

In attaching a 1-in. service-tap to a 3-in. main it is well to tap the main only ¾ in., using an increaser or reducer. In case, however, it is necessary to connect larger services with the main, two or more taps may be made (staggered) and connected into a header, or a split-sleeve may be used and the connection made into it. It is a rule with many gas companies to make the tap for all instances one size less than the size of the service to be run. Where a split sleeve is used a hole corresponding with the size of the service is tapped concentrically with a smaller hole in the main over which it is clamped.

Small gas companies, from reasons of economy, frequently omit service- or curb-cocks on services under 2 in. The use of this cock is, however, better practice.

Coating.—The question as to whether or not wrought-iron service-pipes should be coated depends largely upon the character of soil through which they run. It is certain, however, that in the neighborhood of ice-cream saloons, fish-markets, and localities where the pipe must be exposed through areaways, etc., galvanized iron should be used. The following is a recipe for pipe-coating used by one of the large western gas companies and which can be recommended by the writer:

"Bring a kettle of tar (20-gallon) to a low boiling-point and add 20 pounds of fresh-slaked lime, sifted over the top and worked down. Boil down to a paste or a consistency about midway between tar and pitch. Let it settle for a few minutes, then add 4 pounds of tallow and 1 pound of powdered rosin, stir until they are thoroughly dissolved and incorporated with the tar, then let it cool and settle. Ladle off into barrels. When ready for use, to each barrel of 45 gallons of the above mixture add 4 pounds of crude rubber dissolved in turpentine to the consistency of thick cream. Heat the mixture to about 100 deg. Fahr. and immerse the service-pipe, heated to about the same temperature."

A V-shaped trough will be found convenient for dipping these pipes, although it is better to apply the mixture with a heavy brush, unless the ends of the pipe are capped, as the mixture should be excluded from the interior of the pipe. In making joints care should be taken to see that the threads of the service are free from coating.

Proper cards should be made out for all services and should be indexed and filed. These cards should form a perpetual record, beginning at the installation of the service, showing location, dimensions, cost, etc., to which should be added notes of all repairs, renewals, extensions, and further work.

In connecting old services with new mains, as is the case where larger mains are run to take the place of old ones, the usual practice is to make the final or connection joint with such service, one which can be made without turning either of the runs of the pipe, which are connected together. There are several such joints made and used with wrought-iron or steel pipe, the most convenient being what are known as long-screws or running threads, of which the last named are generally the best, although under some conditions flanged joints or "unions" may be used. Care should be taken where services drip or slope back toward the main that this drip be not affected by the increased diameter of the main.

Freezing.—In putting in gas-piping that will be exposed to extreme cold, such as the risers of street-lamps, mains crossing bridges, and services entering houses, obstructions in pipes from frost may be prevented, either by enlarging the portion of the pipe in which the frost tends to accumulate to a sufficient extent to permit the passage of gas of an adequate amount, after the frost has accumulated on the interior sides of the pipe to a thickness sufficient to form a non-conductor of heat and thereby preventing further formation, or by covering the pipe with some non-conductor which prevents the reduction of the passing gas to a frost temperature. The first arrangement is perhaps preferable, the enlargement of pipes to about two sizes larger generally being found sufficient. It is necessary sometimes when the size of the pipe, as in the case of 16- to 20-in. mains, would render this impracticable, to place hand-holes, **T**'s, or cleanouts in such locations as may be convenient for removing such stoppage after its formation.

Attention has been called to the removal of burrs, left by roller-cutters, from the interior of pipe. This is extremely important, and all wrought-iron pipe after being cut should invariably be renewed, as such burrs not only materially reduce the capacity of the pipe, but form a trap and bearing for the accumulation of all manner of stoppage. A practical fitter who has given the matter careful study has proved by actual measurement that in smaller pipes, $\frac{3}{8}$-in. to 2-in., these burrs will reduce the area all the way from 3.1 to 30.4 per cent., with an average reduction in the range of sizes of 15.25 per cent. Many theoretically good steam and hot-water jobs fail of practical results from no other reason than that the fitter neglected to remove the burrs from the pipe. Not only does the collection of sediment about the burrs choke up the pipe,

but they arrest the flow of water, causing it to stagnate and corrode the pipe at the joints. Gas-service pipes are small in diameter, and burrs left by cutting-wheels reduce the area from 16 to 30 per cent. To maintain effective pressure it is almost imperative that these pipes be reamed.

Forcing-jacks.—The Barrett horizontal jack may be used to considerable advantage for forcing pipe through earth in place of digging a trench for short distances in sandy or clayey soils which are free from stone or other obstruction. They may also be used in forcing pipe under sidewalks and for short distances where tun-

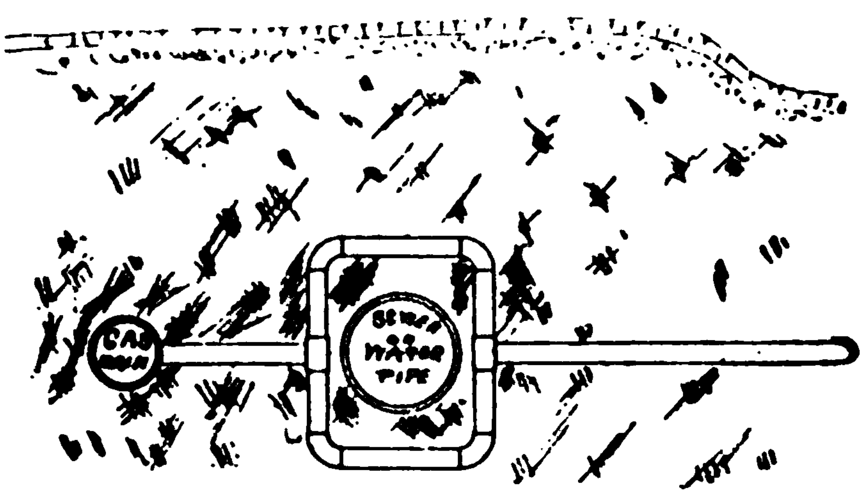


FIG. 42.—Scotch Yoke for By-passing Obstructions when Laying Services.

neling is inconvenient. For a long run, however, this practice is dangerous, there being an opportunity for the pipe to kink, buckle, or trap, or at least not to maintain its proper gradient.

At the meeting of the International Society for Testing Materials in 1900 Professor Howe gave further data from some large-scale experiments conducted by himself, in which he exposed a number of plates of wrought iron, soft steel, and nickel steel $\frac{1}{8}$ inch thick to the action of sea-water, river-water, and the weather for two periods of one year each. The results are summed up as follows:

	Loss by Corrosion.			
	Sea-water.	Fresh water.	Weather.	Average.
Wrought iron	100	100	100	100
Soft steel	114	94	103	103
3 per cent. nickel steel	83	80	67	77
25 per cent. nickel steel	32	32	30	31

Professor R. H. Thurston, from his tests and observation of these materials in practice, concludes on the whole that steel resists corrosion better than iron.

Fittings.—The greatly increased use of high-pressure gas systems throughout the country has made necessary the use of special fittings, especially for service connections, with wrought-iron and

STANDARD DIMENSIONS OF WROUGHT-IRON AND STEEL STEAM-, GAS-, AND WATER-PIPE.

Diameter			Nominal Thickness.	Circumference		Transverse Areas.			Length of Pipe per Square Foot of		Length of Pipe Containing One Cubic Foot.	Nominal Weight per Foot.	Number of Threads per Inch of Screw.
Nominal Internal	Actual External Diameter	Approximate Internal Diameter		External.	Internal.	External.	Internal.	Metal.	External Surface.	Internal Surface.			
In.	Inches.	Inches	Inches	Inches	Inches	Sq. In.	Sq. In.	Sq. In.	Feet	Feet	Feet.	Pounds.	
⅛	.405	.27	.068	1.272	.848	.129	.0573	.0717	9.44	14.15	2513.	.241	27
¼	.54	.364	.088	1.696	1.144	.229	.1041	.1249	7.075	10.49	1383.3	.42	18
⅜	.675	.494	.091	2.121	1.552	.358	.1917	.1663	5.657	7.73	751.2	.559	18
½	.84	.623	.109	2.639	1.957	.554	.3048	.2492	4.547	6.13	472.4	.837	14
¾	1.05	.824	.113	3.299	2.589	.866	.5333	.3327	3.637	4.635	270.	1.115	14
1	1.315	1.048	.134	4.131	3.292	1.358	.8626	.4954	2.904	3.645	166.9	1.668	11½
1¼	1.66	1.38	.14	5.215	4.335	2.164	1.496	.668	2.301	2.768	96.25	2.244	11½
1½	1.9	1.611	.145	5.969	5.061	2.835	2.038	.797	2.01	2.371	70.66	2.678	11½
2	2.375	2.067	.154	7.461	6.494	4.43	3.356	1.074	1.608	1.848	42.91	3.609	11½
2½	2.875	2.468	.204	9.032	7.753	6.492	4.784	1.708	1.328	1.547	30.1	5.739	8
3	3.5	3.067	.217	10.996	9.636	9.621	7.388	2.243	1.091	1.245	19.5	7.536	8
3½	4	3.548	.226	12.566	11.146	12.566	9.887	2.679	.955	1.077	14.57	9.001	8
4	4.5	4.026	.237	14.137	12.648	15.904	12.73	3.174	.849	.949	11.31	10.665	8
4½	5.	4.508	.246	15.708	14.162	19.635	15.961	3.674	.764	.848	9.02	12.49	8
5	5.563	5.045	.259	17.477	15.849	24.306	19.99	4.316	.687	.757	7.2	14.502	8
6	6.625	6.065	.28	20.813	19.054	34.472	28.888	5.584	.577	.63	4.98	18.762	8
7	7.625	7.023	.301	23.955	22.063	45.664	38.738	6.926	.501	.544	3.72	23.271	8
8	8.625	7.982	.322	27.096	25.076	58.426	50.04	8.386	.443	.478	2.88	28.177	8
9	9.625	8.937	.344	30.238	28.076	72.76	62.73	10.03	.397	.427	2.29	33.701	8
10	10.75	10.019	.366	33.772	31.477	90.763	78.839	11.924	.355	.382	1.82	40.065	x
11	11.75	11.	. . .	36.914	34.558	108.434	95.033	13.401	.325	.347	1.51	45.028	8
12	12.75	12.	. . . .	40.055	37.7	127.677	113.098	14.579	.299	.319	1.27	48.985	8

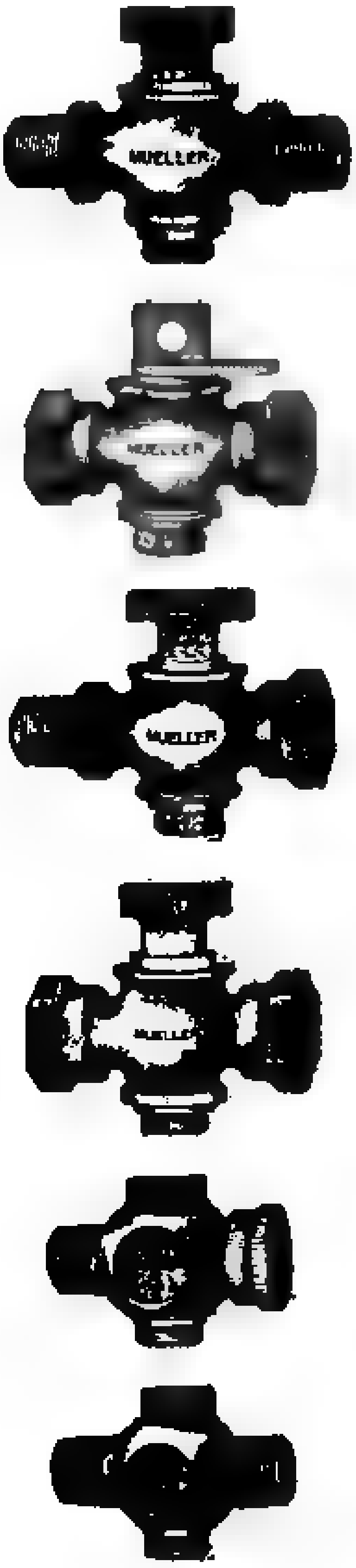


FIG. 43.—Typical High-pressure Cocks

FIG. 44.—Method of Connecting High-pressure Service with Main.

steel pipe. These connections are special patterns and are usually tested under 150 lbs. of air pressure.

The clamps are especially galvanized, and the fittings made of

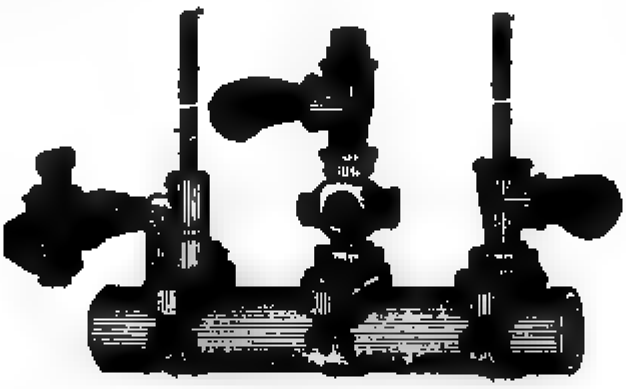


FIG. 45.—High-pressure Cocks Connected in Service-clamps.

material and composition adapted to this class of work, the keys having greater lap and the bodies being carefully ground and oil-polished.

Fig. 45 shows a number of these connections, they being made preferably with a swing-joint. A wooden plug is shown inserted in the hole in the main through the fittings which prevents the escape of gas while the service is being completed, after which it can be removed and the fittings permanently plugged.

Should it become necessary at any time to remove the service-clamp from the main, a wooden plug may be again inserted and the clamp removed without further escape of gas.

Fig. 43 indicates a number of fittings used in this connection,

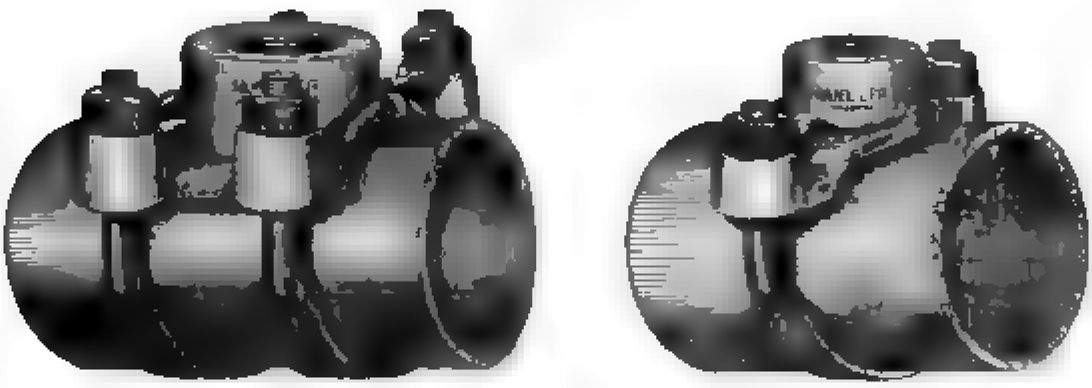


FIG. 46.—Types of Mueller Century Service-clamp

especially manufactured for the purpose, and Fig. 49 indicates the Mueller High-pressure Gas-main Drilling-machine, operating long boring-bars, so that the hole in the main may be drilled through either the clamps illustrated in Figs. 46 and 47, or through any of the fittings of Fig. 43.

This is of especial advantage where exceedingly high pressure

is used, it being good practice to use gas-service cocks in connection with the clamps and tees, both to prevent the escape of gas

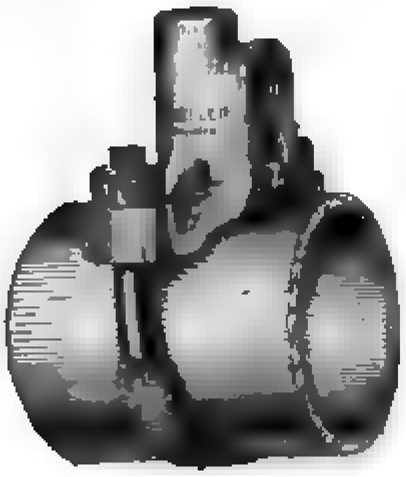


FIG. 47.—Combined High-pressure Clamp and Service Tee.

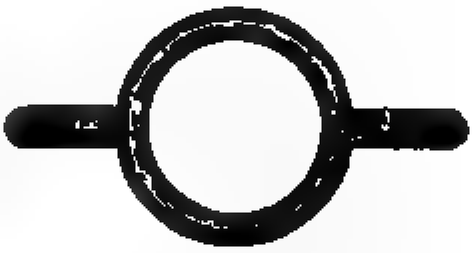


FIG. 48.—Lead Gasket Filling under Saddle of Service-clamp.

and to enable at all times uninterrupted access in the construction or maintenance of the service.

The writer believes that the double clamp, illustrated in Fig.

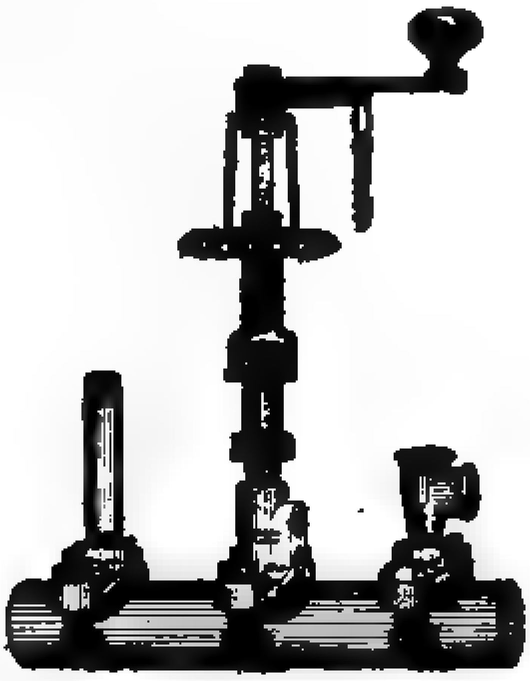


FIG. 49.—Mueller High-pressure Tapping-machine.

46, in connection with the swing-joint and service-cock, illustrated in Fig. 45, is the ideal high-pressure connection.

Where services are to be subjected to pressure of over 20 lbs., extra-heavy wrought-iron pipe or steel pipe, together with extra-heavy fittings, should be used. This is not so much by reason of its safe working-pressure as by the saving in leakage and rigidity attained.

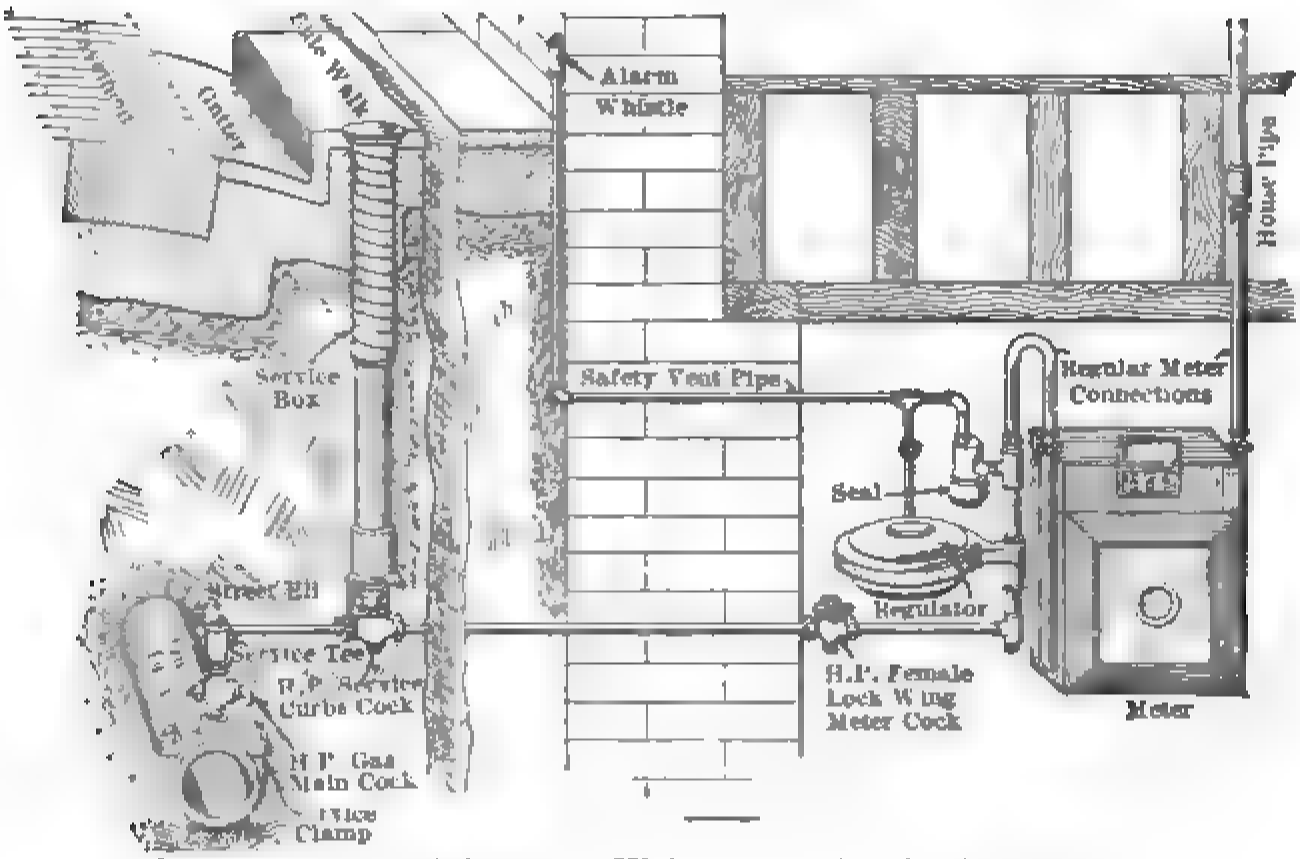


FIG. 50.—General Scheme for High-pressure Service Connection.

High-pressure Service Connections.—The scheme of arrangement for connecting a high-pressure system, as illustrated in the above diagram, Fig. 50, working from right to left, is as follows: On the gas main, which is presumed to be a steel, wrought-iron, cast-iron, or Universal pipe, the yoke service clamp with proper lead gaskets is attached and tightly clamped. The main being tapped through the orifice of the yoke, a high-pressure main cock is inserted, into which in turn is inserted a service tee having one end plugged, and a service ell screwed into its side port. Into this ell the service pipe is screwed and the run of the service taken up to the curb, where a curb cock, protected by a proper service box, is intersected. Continuing the run of the service, it enters the building, and immediately inside the wall a high-pressure female lock-wing meter cock is interposed, from whence the service continues to a tee, one side having a plug or pet cock for dripping purposes, and into the other a riser, which proceeds to the inlet of the regulator. This regulator is of the opposed diaphragm balance-valve type with a by-pass connecting its shell with the safety vent pipe, in case of breakage to the diaphragm of possible leakage. From the outlet of the regulator the riser is connected with a by-pass upon which is placed a mercury seal, which is so designed that in case of "blowing the seal" the mercury will overflow into a receiving trough and by-pass the gas supply to the safety air-vent until replaced into its cup. The function of the seal is to act as an additional safety valve and should have a resistance only slightly above the maximum pressure required at the outlet of the meter, in order that in case of accident occurring to the proper working of the regulator the seal will blow and the gas escape through the fresh-air vent operating the alarm whistle, rather than forcing its way all through the meter and into the house pipe and fixtures. The fresh-air vent should be carried to a considerable height and should not be immediately adjacent to any window, flue, or other orifice in the wall. From the mercury-seal by-pass the gas passes through a regular goose-neck meter connection into the meter and from thence into the main riser of the house pipe.

CHAPTER XV.

CONSUMERS' METERS.

Testing.—All meters, when received from the factory, should be proved before being placed in service. The rating of consumers' meters, as to capacity, is three times its rated capacity of 6 cu. ft. of gas consumption per burner-hour; thus we have in a three-light meter about $3 \times 3 \times 6 = 54$ cu. ft. per hour. In addition to the original test and such test as may be occasioned through complaints and contested bills, each meter should be tested whenever removed and brought to the shop and a record concerning such test be duly filed. Periodically these files should be gone over numerically and all meters which have not been tested within a period of 3 years should be brought to the shop and duly proved. It is good practice to permit a meter to remain in the shops at least 12 hours before proving, in order that there may be an equalization of temperature.

All meters showing a deviation by the prover-test of 2 per cent., either fast or slow, should be corrected or returned to the factory for repairs. Test each meter with gas to see that it registers with a very small consumption (called "check-test"), using a flame not larger than a dime, after which turn off the flame, leaving gas-pressure on meter; this is for detecting any holes in the diaphragm or a leak in the valve. Then test for sticking or irregularity of flow by turning the gas on stronger until the flame should show two small horns. The best way to make this test is to have burners connected up on a header or stand of burners with sufficiently numerous outlets to work the meter to its full capacity.

The third test is the regular one on the prover. When tests are made with the cover on the meter they should be for not less than two revolutions of the test-hand. When the cover is off a satisfactory test can be made with one revolution, this being made by both the "open" and "check" test. Meters showing a variance within 4 per cent. can generally be regulated in the shop, but for more than that amount it is good practice to return them to the factory.

[illegible]

[illegible] should be [illegible]

[illegible]

[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]		[illegible]
[illegible]		[illegible]

[illegible] should be [illegible] in order to prevent [illegible] These [illegible] should also remain in [illegible] Every consumer's [illegible] supported in position by a [illegible] to hang on its own [illegible]

[illegible] immediately when purchased and [illegible] them in a meter-record book [illegible] This is of the utmost importance. In the case of a [illegible] or one otherwise destroyed, a proper [illegible] all details upon this register.

In [illegible] an invoice should be [illegible] and the reading of the

index. The returns made by the repair shop should be carefully preserved. Every meter should thus *be accounted for either as set (as shown by route book and consumer's ledger), in stock, sent away for repairs, destroyed, or condemned.* With the meter-badges on hand this should account for the whole number of badges. As a general rule all meters not being used should be removed and put in stock.

Meter Connections.—Meter connections should be made of uniform length so that they will be interchangeable. They should not be too short, as they are then hard to bend without buckling. A good length for the smaller sizes is 12 in. and for the larger sizes 14 in., 16 in., and 18 in. When a meter is removed for an indefinite period the lead connections and cock should be removed and the service and riser capped or plugged. Meter connections should be made as follows:

SIZE OF METER CONNECTIONS.

Size Meter.	Diameter of Iron Pipe. Inch.	Diameter of Cock. Inch.	Diameter of Lead Pipe. Inch.
3-light	3/4	3/4	5/8
5-light	3/4	3/4	3/4
10-light	1	1	1

Meters rated at 30 lights and over should be provided with screw connections instead of lead. Only standard connections

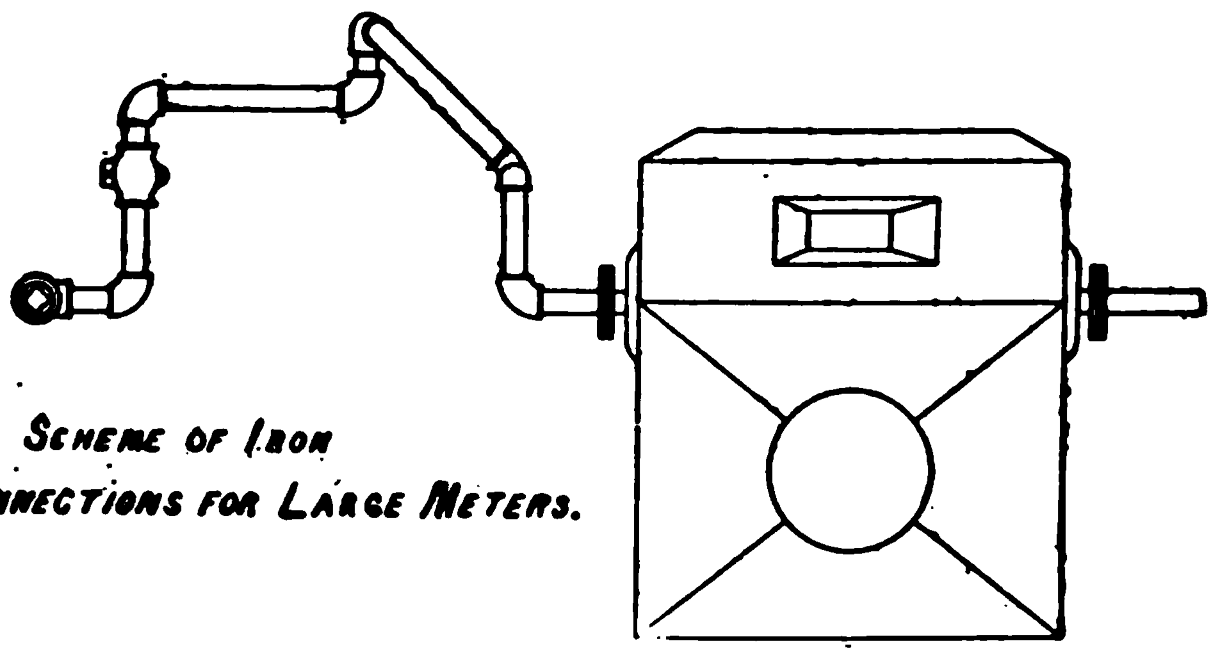


FIG. 51.—Iron Meter Connection.

should be used and a set of hard-brass standard gages should be provided in every meter-shop. All new meters and unions should

immediately upon receipt from the factory be tested with these gages, and failing in standard should be rejected.

The gage consists of two parts, a screw and a nut. The threads of the screw are exactly standard; the countersink in the end of the screw is the diameter of the nose of the swivel. The nut is made to fit the standard screw exactly, and the hole in it is a gage for the swivel. The standard dimensions of unions for 3-, 5-, and 10-light meters are as follows:

METER UNION STANDARDS.

	3-light.	5-light.	10-light.
Number of threads per inch	18	12	$11\frac{1}{2}$
Diameter of screw, inch	[illegible]	1 [illegible]	1 [illegible]
" " swivel or nipple, inch	[illegible]	[illegible]	1 [illegible]
" " nose of swivel, inch	[illegible]	[illegible]	1

Frost and naphthalene can be removed from meters by pouring in the inlet a small quantity of wood alcohol or benzine. The process of injecting alcohol in a vaporized condition into the main, as described elsewhere by the writer, has an exceedingly beneficial effect upon the meters in softening the diaphragm and removing tar, naphthalene, and frost.

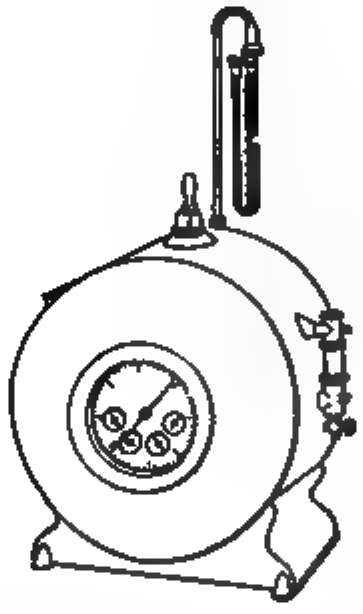


FIG. 52.—Test-meter.

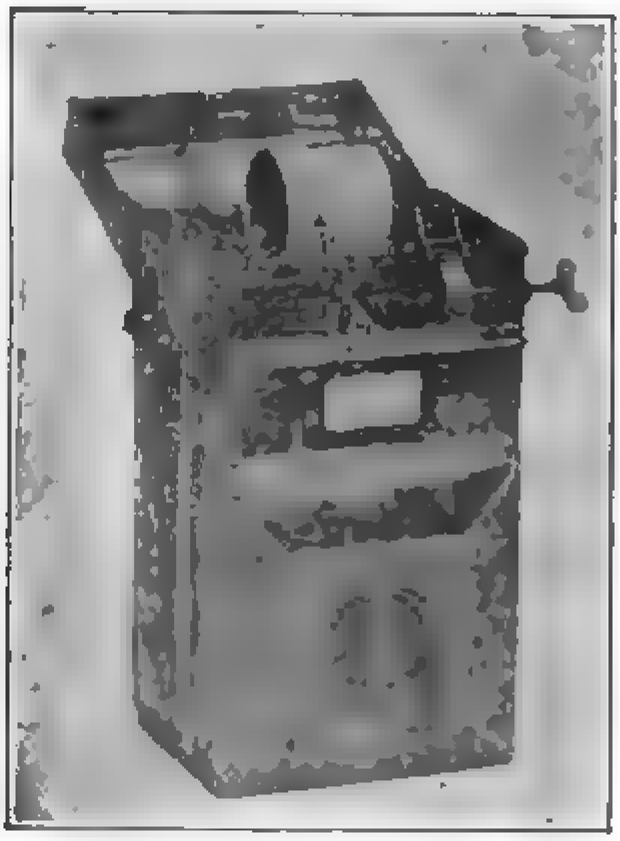


FIG. 53.—Complaint Meter.

Meter-readers should be prevented from using matches in reading meters; proper lanterns (Davy safety-lamp type) being sub-

stituted, by reason of the danger of explosion and ignition from leaks. It is also well to reverse meter-takers upon their routes in order that each meter-taker may be familiar with the entire system, and also to prevent the putting down of "fake" readings, which is a great temptation to the meter-taker where meters are placed in inconvenient localities.

Meter connections, when of lead, should be made of the following class of lead pipe:

$\frac{5}{8}$-in. pipe for 3-light meters, $1\frac{1}{4}$ lbs. per ft., known as "C" pipe.

$\frac{3}{4}$-in. pipe for 5-light meters, $1\frac{3}{4}$ lbs. per ft., known as "C" pipe.

1-in. pipe for 10- and 20-light connections, 2 lbs. per ft., known as "D" pipe.

This pipe is to be used when the meter has a sound support, but in instances where the connections are liable to have to carry all or a large part of the weight, "B" pipe should be substituted for the "C" pipe in the above, and "C" pipe for "D" pipe. It is much better practice, however, to place heavy shelves or brackets beneath the meter, and these should be invariably required.

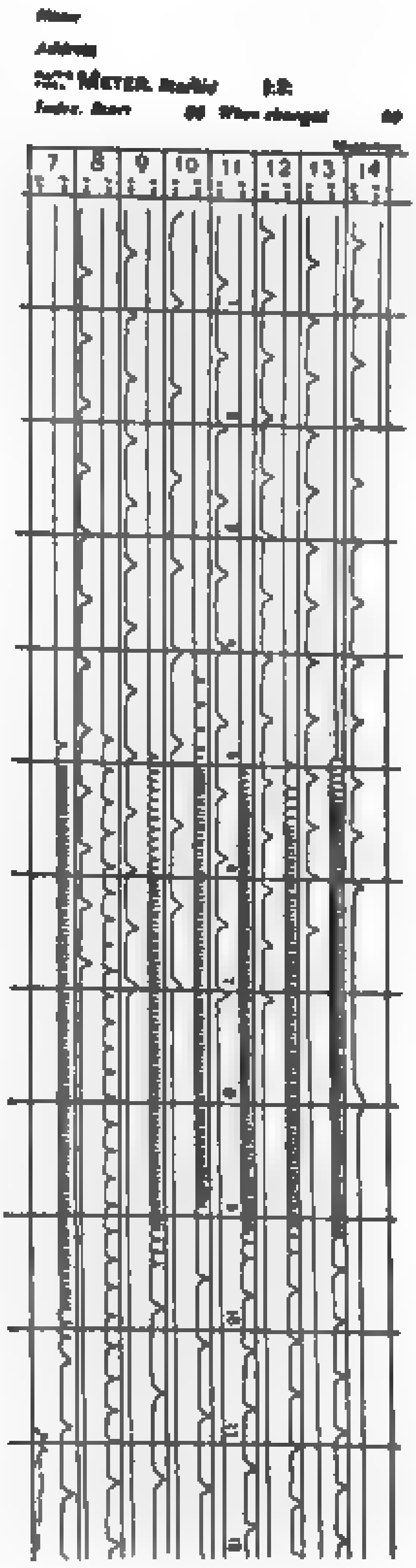


FIG. 54.—Record from Complaint Meter.

Operation. — While two-diaphragm meters have been known to withstand a gas pressure of 18 to 20 in., they should under no condition be subjected to such a strain; the maximum should not exceed 5-in. water-column pressure and the differential or difference in pressure between the inlet and outlet of the consumer's meter should not exceed 0.2 of an inch.

The drop in candle power after leaving the works, in the case of water-gas, is in some degree a definite function of atmospheric temperature and barometric pressure and will, to a certain extent, occur in spite of the most thorough fixing and careful condensation.

Consumers' dry-meters should never be set so that the consumer can readily twist it upside down, without detection, as in

this case the valves are apt to fall from their seats and hang down, thus permitting the free passage of gas without registration. When a consumer's meter is found inaccurate, it is frequently the case that there is considerable difference between the "open" test and the "check" test—the latter being the test of the meter under only a small portion of its capacity. The check test is invariably the most exacting, putting a severer requirement upon the meter and thereby developing more fully the presence of any internal leaks. Again, the time period being longer, there is greater opportunity for any lack of fitting on the part of the valve, due to dirt or wear or any wear or lack of adjustment in the tangents, to be manifested.

In addition to the regular consumer's meter a complaint meter is manufactured by the Maryland Meter Co. It will be found of considerable use in checking up complaint bills, locating hour of peak-load in certain buildings, and as a "tell-tale" (Fig. 53, page 212).

In addition to this, every gas company should be equipped with one or more wet- or test-meters (Fig. 52), which will be found of service in all sorts of portable testing, settlement of complaints, determination of leaks, etc. Its minute subdivision of scale makes it of great value in this line.

Another reason for the difference in registration in the "open" and "check" test of consumer's meter is probably a difference in the distension of the diaphragm-skins during the tests, the distension generally being greater during the open than the check test. This discrepancy should not vary over 0.03 per cent. either way; it may usually be corrected by softening the solder with a hot iron and moving the tangent slightly on its axis, the difference in the axis of the tangent compensating for this irregularity in the skins, which difficulty becomes more marked, as they harden from age, oxidation, or condensation.

Since the days of Glover, there has been but little change in the type and manufacture of the consumer's meter. The inaccuracies due to water evaporation, the corroding action of the various elements upon the metal material, together with the facility with which the wet-meter could be "doctored," has practically put that type of meter out of current use. There is perhaps no other mechanism of its class which has endured the test of time with so little change in its original design as the dry-meter, which is practically identical in construction as manufactured both in this country and abroad.

The most radical departure from the orthodox standard in this line has been made by the H. H. Sprague Co. of Bridgeport, Conn., whose meter has now stood the test of service for some three years. The Sprague Co. furnish nipples and unions, which make

their meters adaptable to any class of standard connections, thereby making them interchangeable with the older types. Their No. 1 meter has the capacity of the 3-, 5-, and 10-light, old style, while the No. 2 is equal to the former 30-light; other sizes are now in process of design.

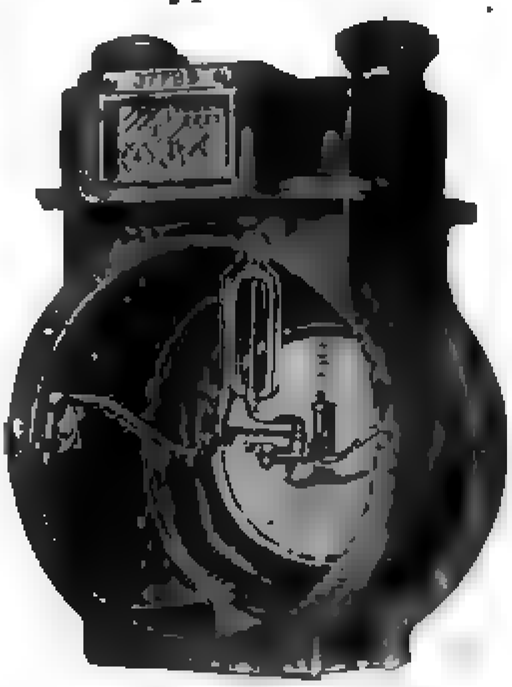


FIG. 55.—The Sprague Meter of Bridgeport, Conn.

Meter-testing Corrections.—In using a small gas-holder or prover it is often found that the temperature of the gas passing through the meter is greater or less than that found in the holder, and this may make some difference where accurate work is desired. For example, the following table shows the percentage increase in volume of gas at various temperatures over that at freezing; it was compiled from English figures. Hence, for ordinary purposes and ordinary temperatures, corrections may be made on the assumption that 4° Fahr. increase or decrease in the temperature of air or gas produces 1 per cent. variation in the volume of such air or gas, or 1° produces a difference of 0.0025 per cent.

Temperature in Fahrenheit's Scale.	Percentage of Expansion.	Temperature in Fahrenheit's Scale.	Percentage of Expansion.	Temperature in Fahrenheit's Scale.	Percentage of Expansion.
31.40	0	54 33	5 5	74.30	11.0
33.54	0.5	56.24	6.0	75 94	11.5
35.70	1.0	58 12	6.5	77 23	12.0
37.84	1 5	60 02	7.0	78.81	12.5
39 91	2.0	62.00	7.5	80.40	13.0
42.05	2 5	63 77	8.0	81.94	13.5
44 17	3 0	65 63	8.5	83.44	14.0
46.22	3.5	67 43	9.0	84.88	14.5
48 25	4 0	69 18	9 5	86.39	15.0
50.32	4.5	70.90	10 0	87 83	15 5
52.36	5.0	72.60	10.5	89.20	16.0

Thus if the holder temperature is 59°, that of the meter 61°, when the meter registers 5 cu. ft., the holder indicates 4.9 cu. ft. Then $4.9 \times 2 \times 0.0025 = 0.025$, which must be added to the holder indication, making 4.925 cu. ft., which is 0.075 cu. ft. fast, or 1.42 per cent. If the temperature of the meter is the lower, the correction for the volume must be subtracted instead of added to get the correct holder indication.

CHAPTER XVI.

PRESSURE.

The question of pressure is one which must be determined solely from local conditions, the basis of which must necessarily be the extreme terminus of the distribution system, or, in other words, the minimum pressure must be the unit from which all calculations are to be made.

Adequate Pressure.—Pressure can at all times be reduced through means of district or house governors, but the initial pressure is only increased by an elevation in topography, which is equivalent approximately to 0.1 in. of water for each rise of 15 ft. above the outlet of the holder. On the other hand, the loss of pressure due to friction is enormous, which reduction is materially increased by sharp bends in the pipe-line. The initial pressure, therefore, must be governed by the minimum pressure allowable or the pressure that is necessary to deliver in the most remote sections of the system.

Loss of pressure through friction can, of course, be largely obviated by increasing the diameter of the main, the capacity of gas-pipes varying as the square root of the fifth power of the diameter. The most convenient way for maintaining an equalized pressure throughout an entire system is to establish a series of testing-stations, or of locating Bristol recording gages in various localities and observing from these the minimum pressure prevailing at "peak of load" hours.

In using the expression "minimum pressure" the writer means the peak of the load-line as observed on a Bristol chart during the heaviest day's consumption during the year. A record of these tests should be kept from year to year, as an increase of consumption in any district, or other district adjacent or connected thereto, will cause so material a drop in pressure as to seriously affect the service, and if a comparison is kept up throughout the lighter burning months, together with previous records, such a drop may be anticipated and larger mains, or other expedients such as cross

connections, the running of feed-lines, or the tapping in of a booster-line or high-pressure line, can be arranged.

To facilitate calculations as to the size of pipe requisite, a Cox gas-flow computer can be had from any of the gaslight journals which will be found very convenient in determining the size and pressure drop in various pipes.

Pressure is also frequently affected by traps of tar or other condensation occurring in the pipes, and of a failure to pump drips at proper intervals. A regular card system should be maintained containing a record of the pumping of each drip, its location, capacity, etc., and these drips should be gone over periodically.

The question of house pressure, or burner pressure, is a vital one and of constant occurrence in the handling of complaints. In the examination of poor lighting conditions in a house or other installation, the pressure test should be a first consideration. The first test should be made on the service side of the meter and a record made thereof. The next test should be made on the house side of the meter, and a simple deduction of the two readings will indicate the loss of pressure due to the meter normally, 0.2 in., sometimes caused by a stoppage, condensation, breaking of parts, or a stiffening of the meter-diaphragm. It must be remembered that loss of pressure is invariably due to friction, and that without a flow of gas no friction can exist. Therefore, in order to make any pressure-test, it is necessary to create a gas flow, which is best done by lighting all the burners possible in the installation and thereby obtaining the reduction of pressure at maximum demand. A comparison can then be made by gradually reducing the amount of consumption and noting the ratio of reduction of friction and increase of pressure, this being an invariable test for piping which is too small, stopped, etc., etc. The pressure reduction between full load and no load on any system should be less than 20 per cent. A finely calibrated water-gage, carefully read throughout the branches of a house-system, will indicate at just what point the friction is extreme or first evident.

A careful investigation of the distribution conditions of a number of cities, and an examination into the nature, construction, and capacity of a number of gas appliances, pipe systems, etc., goes to show the necessity of a maintenance at the consumer's meter of a pressure not less than 2 in. The maximum pressure is, of course, a matter of local conditions and necessity, the minimum being the unit of consideration and calculation. It should on low-pressure systems be at least less than 4 in. and preferably under 3 inches on account of leakage.

It is, of course, understood in all references to pressure that the weight of a column of water 27.77 inches in height is 1 lb. per sq.

in., one inch, therefore, being 1/27 pound. Correlatively, 1 ounce per sq. in. = 1.74 inches water pressure. Generally 0.036 time the height of water-column in inches equals the pressure of water in lbs. per sq. in.

It will be found convenient when investigating poor pressure to take the pressure of adjacent services before taking the house-pipe pressure and by comparison locate stoppages, should there be any, in the service or the immediate district of the main.

Governors.—The rattling or vibration of the dry-pressure regulator or governor is invariably caused by its being insufficient in size, either to pass the amount of gas demanded or to accommodate a pressure considerably in excess of that for which the governor was designed. The matter may be corrected either by putting in a governor or regulator of larger capacity, or by placing two or more governors in series.

Two cuts of governors are herewith appended (Figs. 56, 57), namely, the Automatic and the Foulis air control governors. The

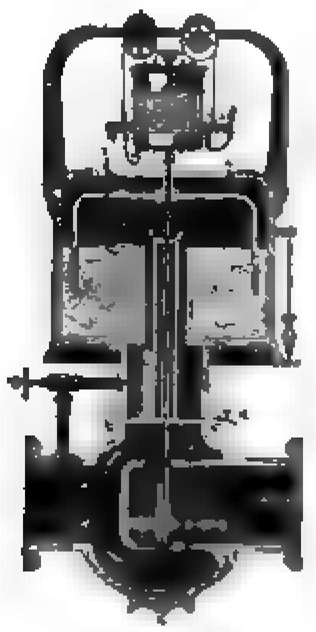


Fig. 56.—Connelly Automatic Station Governor.

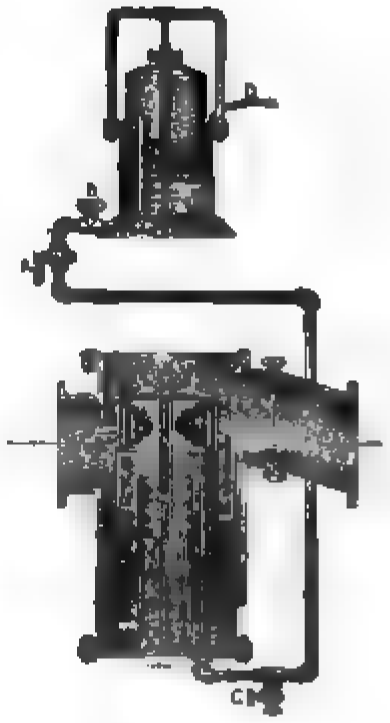


Fig. 57.—Foulis Street Governor.

objection to the Automatic governor is: Where peak loads come on suddenly and from widely outlying districts, the pressure-area must become low throughout the entire system before the governor responds, thus making the response regulation somewhat slow. The tendency with an automatic governor is naturally not to give it the close attention which is demanded by the hand control, and in this connection the action of the Foulis regulator is accurate and simple,

permitting a wide range of adjustment. This governor is especially favorable to situations on high-pressure, or booster, lines; it is applicable to street manholes, the air-line being run to some convenient point within a radius of 1000 yards.

Excellent house or local governors are made by the Connelly Company and the Chaplin & Fulton Company.

Pressure-gages.—The differential pressure-gage illustrated by Fig. 59, as designed by the writer some years ago, has been found of extraordinary value in the location of stoppages, back pressure, etc., throughout the apparatus and connections of gas-works. It consists of a series of any number of brass **T**'s (*A*), connected together by short nipples, and the whole clamped for convenience against the pressure-board. In the center a large **U** pressure-gage (*B*) is connected, having a capacity up to several pounds and graduated down to 0.1 in. water pressure.

Cut into the riser of the gage at *E* is a relief-cock, to relieve compression between making tests and to permit the fluid in the gage to return to zero.

A number of pressure-lines, which may be as small as $\frac{3}{4}$-in. pipe (*D*), are run from various portions of the works from different apparatus and sections of mains. These should be properly labeled and are connected into the male outlet of the **T**'s, brass cocks (*C*) being interposed.

It will now be evident that by switching-in upon the gage, one at a time, any one of these pressure-lines, and by noticing the difference in pressure between two or more, the approximate location of any stoppage or back pressure may be immediately located and the difficulty eventually corrected.

On mains where there are no high-pressure booster-lines or sub-station governors it is often difficult at the works to determine exactly the hours of peak load and the moment of maximum demand. To overcome this difficulty, and to indicate at the holder any increase or demand, requiring additional pressure and supply, W. A. Baehr, of the Laclede Gaslight Co., has designed the following device. His idea is that the essential principle of pressure regulation is to maintain a certain pressure at the consumers' meters, within a small percentage either way of a fixed pressure, and as the consumption increases or decreases, the holder pressure should be correspondingly raised or lowered. This is usually accomplished by placing recording pressure-gages in the various districts supplied by the holder, and by raising or lowering the holder pressure to supply the demand, as reflected from the charts of these gages, until the best average for the entire district so supplied is reached.

It is, of course, obvious that the same condition of consump-

tion never obtains on successive days or months, and therefore Mr. Baehr has arranged an automatic indicator in the outlet-pipe of his holder. This consists of a Pitot tube facing the holder.

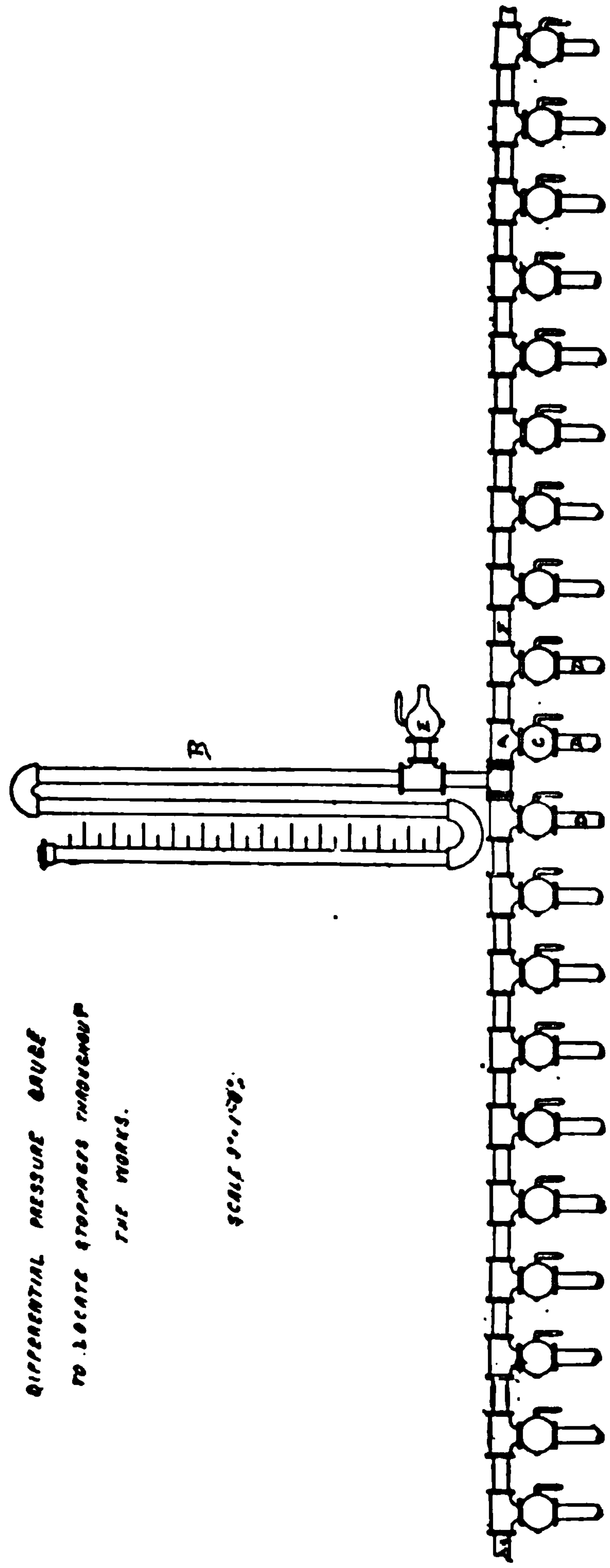


FIG. 59.—Multiple-connection Pressure-gage.

The opening in the tube, which faces the stream of flowing gas, gives the pressure due to the sum of the static head plus the impact or velocity head; whereas the side opening gives the pressure due to the static head only; therefore any variation in the way

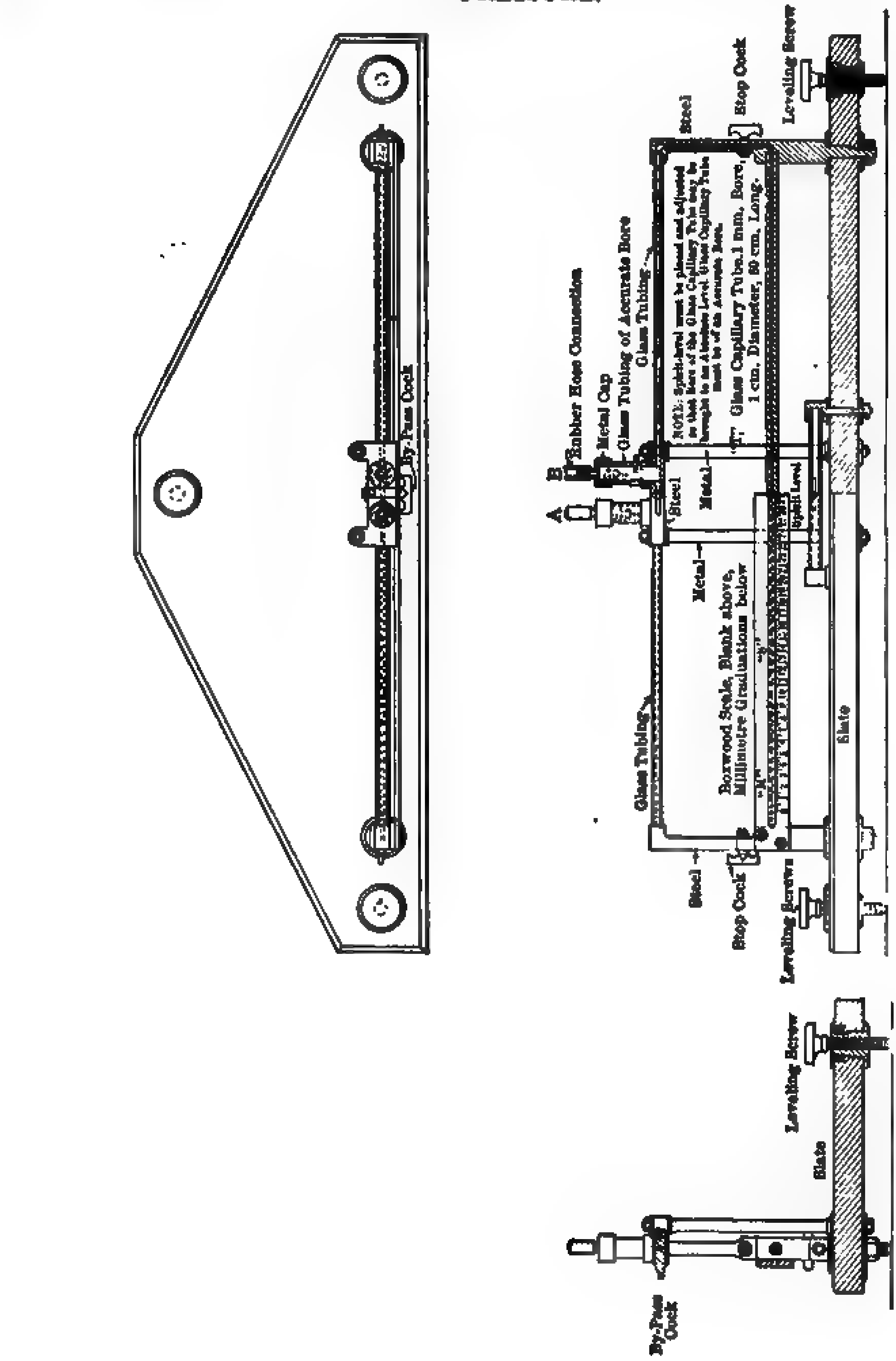


FIG. 60.—Differential Pressure-gage for Use with the Pitot Tube (Laclede Gaslight Co.).

of flow of gas is at once reflected by the variation in differential pressure between the two openings of the Pitot tube. By using a

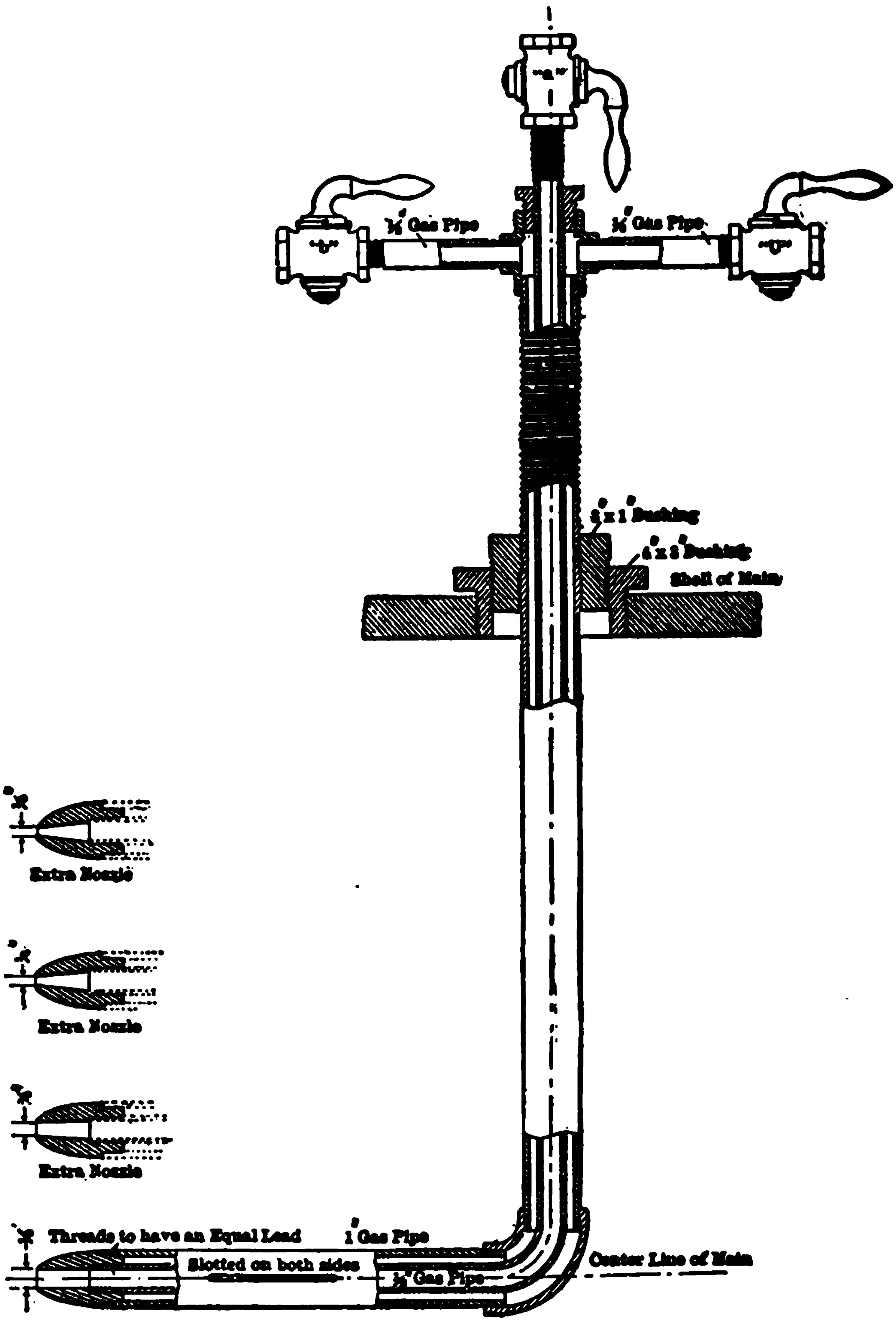


FIG. 61.—Pitot Tube for Measuring Velocity-head of Gas Flowing in Pipes.

very sensitive differential pressure-gage the variations of flow can readily be observed. It is of course necessary to calibrate these gages for each particular holder, in order to read direct or to ascer-

tain the variation in pressure of the holder necessary to supply any particular demand. The Laclede Gaslight Co. of St. Louis, Mo., use three types of sensitive differential gages, provided with two scales, one of which shows a division in millimeters and the other reading gives directly the proper pressure to be carried on the holder outlets.

An excellent ink for recording-gage pens may be made of glycerine, colored with a solution in alcohol of fuchsine, cochineal, or any other aniline coloring-matter, a sufficient quantity being added to bring it to proper viscosity.

It will be kept in mind that increasing the pressure increases the consumption, and that main and pipe leakage increase at the same time.

Engine Pulsations.—It is often the case, where a gas-engine is connected to a comparatively small street main, for its operation (especially where this engine is of multiple-cycle type) to cause a considerable pressure fluctuation in the adjacent gas supply, causing disturbance of the district lighting. To correct this there are various devices, some of which are: Connecting two large gas-bags to the pipe, between the engine and the gas-meter; or putting in two pipes of three or four times the diameter of the engine supply-pipe between the engine and meter, or meter and service; or cutting in a stop-cock after the meter, and turning this down in such a manner as to supply the gas-bag or bags at a practically uniform rate, and therefore make a practically continuous flow of gas. The best method, especially in the use of multi-cylinder engines, is to have a miniature holder, the seal consisting of some non-volatile liquid. In the interval of the strokes of the engine the supply of this reservoir is replenished, and the pressure of the atmosphere against this seal and holder crown tends to cushion any pulsation which may occur. This is unquestionably the best form of vibration reducer, but somewhat expensive. An old meter-prover may be utilized, however.

The ordinary form of draught-gage, consisting of a **U** tube containing water, lacks sensitiveness when used for measuring small quantities of draught. The Barrus draught-gage multiplies the indication of the ordinary **U** tube as many times as may be desired. This instrument consists of a tube, usually made of $\frac{1}{2}$-in. glass, which is surmounted by two glass chambers having a diameter of about $2\frac{1}{2}$ in., being arranged in the manner shown in Fig. 62. It is placed in a wooden case provided with a cover, the outside dimensions being $6\frac{1}{2}\times20$ in.; this is screwed to the wall in an upright position. Two different liquids, which will not mix and which are of different color, are used for filling the instrument, one occupying the portion AB and the other, which is the heavier

of the two, the portion BCD. When the right-hand tube is connected to the flue, the suction produced by the draught draws the line of demarcation B downward, and the amount of motion is proportional to the difference in the areas of the two chambers and of the **U** tube, modified somewhat by the difference in the specific gravity of the liquids. By referring to the scale on the side the amount of motion is measured. This scale is movable, and can be adjusted to the zero-point by loosening the thumb-screws. The liquids generally employed are alcohol colored red and a certain grade of petroleum oil. A multiplication varying from 8 to 10 times is obtained in the instrument shown; in other words, with ¼-in. draught, the movement of the line of demarcation is from 2 in. to 2½ in., the exact amount of multiplication being determined by calibration referred to a standard instrument.

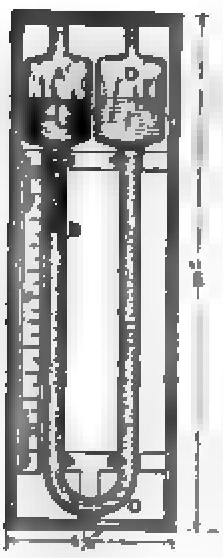


Fig. 62.—Barrus Draught-gage.

High Pressures.—In conditions of high-pressure distribution where gas governors or regulators are used and the initial pressure exceeds over, say, 10 inches of water, the pressure regulator or governor should be reinforced by a mercury seal and escape pipe or vent, which acts as a safety-valve or relief, saving the meter or house fixture from excessive strain, in case of a failure on the part of such regulator to work, or rather to reduce the pressure.

It is the writer's practice, however, to merely connect-in the governor or regulator directly to the service, interposing only a proper service-cock, then between the governor and the consumer's meter to interpose the seal-pot in such manner that excessive pressure escaping from the outlet of the governor shall blow the seal and escape through the vent-pipe into the open air; it being well to place an alarm whistle on the outlet of such pipe to give warning of the escaping gas and the general condition of affairs.

In calculating the discharge from pipes conveying gas under higher pressures than usual, the following formula is used, a slide-rule computer having also been made from it:

COX'S HIGH-PRESSURE DISCHARGE FORMULA.

$$V = 33.3\sqrt{\frac{d^5(P_1^2 - P_2^2)}{LW}},$$

where V = discharge in cubic feet per hour at atmospheric pressure;
d = diameter of pipe in inches;
P_1 = absolute initial pressure in pounds per square inch;
P_2 = absolute terminal pressure in pounds per square inch;
L = length of pipe in miles;
W = specific gravity of gas when air = 1.

Where it is desirable to transmit gas under a higher pressure than ten pounds per square inch, positive pressure-pumps of the Westinghouse air-brake compressor type or the Laidlaw-Dunn-Gordon Company's will be found most efficient and satisfactory. For lesser pressures heavy-duty exhausters (see chapter on Exhausters) may be used.

Generally speaking, the exhauster is employed where volume is the consideration, and the compressor for pressure.

Cox's Compressed-air M.E.P. Computer.—This computer is designed to give the theoretical mean effective pressure due to the adiabatic compression of air from any initial to any final pressure, and for any altitudes up to 15,000 feet. It solves the formula

$$\text{M.E.P.} = 3.463\ P_1 \left\{ \left(\frac{P_2}{P_1}\right)^{.29} - 1 \right\},$$

where P_1 = initial absolute pressure, and

P_2 = final absolute pressure.

It also gives the M.E.P. for 2-, 3-, and 4-stage compression reduced to the low-pressure cylinder, assuming that the number of compressions in each cylinder is the same (this combination being the most economical). It is also assumed that the intercooling reduces the temperature of the air in each cylinder to that at which compression in the first cylinder began.

It further gives the horse-power developed in compressing 100 cubic feet of free air to the given final gage pressure.

DIRECTIONS FOR 1-STAGE COMPRESSION.

1. Set the initial gage pressure on the bottom scale of the disk to the ratio of the absolute pressures, that is P_2 divided by P_1. This ratio may be calculated or taken at once from column 2 of the table accompanying the indicator.

2. Opposite the arrow on the disk marked 1-STAGE find on the top scale the theoretical mean effective pressure in pounds per sq. in. for the whole stroke.

FOR 2-, 3-, OR 4-STAGE COMPRESSION.

1. Set the initial gage pressure of the first or low-pressure cylinder on the bottom scale of the disk to the ratio of the absolute pressure in each cylinder, taken from columns 3, 4, or 5 of the table, according to whether the compression is to be by 2, 3, or 4 stages.

2. Opposite the arrow on the disk marked 2-, 3-, or 4-STAGE (according to the number of compressions decided upon) find on

the top scale the theoretical mean effective pressure for the whole compression, reduced to the low-pressure cylinder.

Note.—When compressing from atmospheric or normal pressure, the initial gage pressure to be used as above is zero GAGE, except when seeking the M.E.P. for a given altitude, in which case the given altitude must be set opposite the pressure ratio, instead of zero initial gage pressure.

To find the horse-power developed in compressing 100 cubic feet of free air to the given final gage pressure, set the edge marked M.E.P. of the small sector to the ascertained M.E.P., then opposite the arrow find the D.H.P.

The following data, from a paper read by W. A. Learned before the New England Association of Gas-engineers, give some idea of the influence of compression upon city gas:

CONDENSATION DUE TO COMPRESSION OF GAS.

Gas Compressed, Cubic Feet.	Compression, Pounds per Square Inch.	Water Condensed, Ounces	Hydrocarbons Condensed, Ounces.	Condensed Hydrocarbons, Specific Gravity.	Fractional Distillation of Hydrocarbons which were Condensed, Degrees Fahr and Per Cent.							
					232°.	246°.	271°.	282°.	309°.	318° to 331°.	354° to 370°.	Residue and Loss.
39,000	5	150	41 5	0 894	..	7 5	19 25	10	15 60	14 13	19.15	14.37
39,800	10	179	11.2	0.886	6 5	16.3	17 4	0	16.9	13 9	20.8	8.2
38,200	20	280	19.9	0.889	12	18	20.9	6	10	11.8	13.2	8.1

EFFECT OF COMPRESSION ON CANDLE POWER OF GAS.

Gas in Holder.	Gas Pressure in Pounds per Square Inch.				Kind of Gas.
	5.	10.	[illegible]	30.	
	c. p.	c. p.	c. p.	c. p.	
14.8 candle power...	....	13 2	... .	......	Coal-gas.
16.14 " " ...	......	15 73	.. .	......	"
17.59 " " ...	......	18.09	16.05	......	23 per cent water-gas.
18.56 " " ...	......	......	15.48	15.02	22 " " "
17.10 " " ...	17.30	16.15	...	....	29 " " "

The increased candle power and brilliancy at 5 lbs. compression can be accounted for by the decrease of the moisture in the gas. Many attempts have been made to dry the gas, with the result that when it was deprived of its moisture the illuminating power was increased to a considerable extent.

The following analyses were secured through the courtesy of W. R. Addicks and were made by J. F. Wing, chemist.

CHEMICAL ANALYSES OF COMPRESSED GAS.

	Gas from Holder.	Gas Compressed, Pounds per Square Inch.		Gas from Holder.	Gas Compressed, Pounds per Square Inch.	
		10.	20.		20.	30.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
CO_2	2.5	2.3	2.4	2.0	2.0	2.1
Illuminants	6.0	6.0	7.0	6.7	6.5	6.7
O_2	0.2	0.0	0.0	0.0	0.0	0.0
CO	12.3	12.3	12.2	12.6	13.3	12.4
H_2	50.6	50.2	47.3	49.2	49.1	46.6
CH_4	26.4	26.7	25.0	28.0	27.1	27.6
N_2	2.1	2.0	5.7	1.5	2.5	4.7
Total	100.1	99.5	99.6	100.0	100.5	100.1
Candle power	17.6	18.1	16.06	18.59	15.48	15.02

VALUES OF A GIVEN QUANTITY OF GAS AT DIFFERENT PRESSURES.

Capacity of a Vessel in Cubic Feet.	Containing Gas under a Pressure of	Will Contain the Following Cubic Feet of Gas.
100	4 oz.	100.
100	8 "	104.
100	16 "	106.
100	1.5 lbs.	109.1
100	2 "	111.8
100	5 "	125.
100	10 "	140.
100	15 "	200.

REGISTRATION OF GAS BY METER UNDER DIFFERENT PRESSURES.

Pressure in Ounces per Square Inch.	Relative Density.	Cubic Feet of Gas.	
		Passed.	Registered.
1	0.987	0.500	0.507
1.5	0.989	0.612	0.621
2	0.991	0.707	0.713
3	0.996	0.866	0.869
4	1.000	1.000	1.000
5	1.004	1.118	1.113
6	1.009	1.225	1.214
7	1.013	1.323	1.306
8	1.017	1.414	1.390
9	1.022	1.500	1.468
10	1.026	1.581	1.541
11	1.030	1.658	1.610
12	1.034	1.732	1.675

THE EQUIVALENT OF OUNCES PER SQUARE INCH PRESSURE IN INCHES OF WATER AND OF MERCURY.

Ounces.	Inches of Water.	Inches of Mercury.	Ounces.	Inches of Water.	Inches of Mercury.
1	1.7	0.125	9	15.5	1.125
2	3.4	0.250	10	17.2	1.250
3	5.2	0.375	11	19.0	1.375
4	6.9	0.500	12	20.8	.500
5	8.6	0.625	13	22.5	1.625
6	10.3	0.750	14	24.2	1.750
7	12.0	0.875	15	26.0	1.875
8	13.8	1.000	16	27.7	2.000

These conversion tables are often useful in natural-gas distribution:

HEIGHT OF WATER COLUMN IN INCHES CORRESPONDING TO VARIOUS PRESSURES IN OUNCES PER SQUARE INCH.

Pressure in Ounces per Square Inch.	Decimal Parts of an Ounce.				
	0.0	0.1	0.2	0.3	0.4
0	......	0.17	0.35	0.52	0.69
1	1.73	1.90	2.08	2.25	2.42
2	3.46	3.63	3.81	3.98	4.15
3	5.19	5.36	5.54	5.71	5.88
4	6.92	7.09	7.27	7.44	7.61
5	8.65	8.82	9.00	9.17	9.34
6	10.38	10.55	10.73	10.90	11.07
7	12.11	12.28	12.46	12.63	12.80
8	13.84	14.01	14.19	14.36	14.53
9	15.57	15.74	15.92	16.09	16.26

Pressure in Ounces per Square Inch.	Decimal Parts of an Ounce.				
	0.5	0.6	0.7	0.8	0.9
0	0.87	1.04	1.21	1.38	1.56
1	2.60	2.77	2.94	3.11	3.29
2	4.33	4.50	4.67	4.84	5.01
3	6.06	6.23	6.40	6.57	6.75
4	7.79	7.96	8.13	8.30	8.48
5	9.52	9.69	9.86	10.03	10.21
6	11.26	11.43	11.60	11.77	11.95
7	12.97	13.15	13.32	13.49	13.67
8	14.71	14.88	15.05	15.22	15.40
9	16.45	16.62	16.79	16.96	17.14

PRESSURES IN OUNCES PER SQUARE INCH CORRESPONDING TO VARIOUS HEADS OF WATER IN INCHES.

Head in Inches.	Decimal Parts of an Inch.									
	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0		0.06	0.12	0.17	0.23	0.29	0.35	0.40	0.46	0.52
1	0.58	0.63	0.69	0.75	0.81	0.87	0.93	0.98	1.04	1.09
2	1.16	1.21	1.27	1.33	1.39	1.44	1.50	1.56	1.62	1.67
3	1.73	1.79	1.85	1.91	1.96	2.02	2.08	2.14	2.19	2.25
4	2.31	2.37	2.42	2.48	2.54	2.60	2.66	2.72	2.77	2.83
5	2.89	2.94	3.00	3.06	3.12	3.18	3.24	3.29	3.35	3.41
6	3.47	3.52	3.58	3.64	3.70	3.75	3.81	3.87	3.92	3.98
7	4.04	4.10	4.16	4.22	4.23	4.33	4.39	4.45	4.50	4.56
8	4.62	4.67	4.73	4.79	4.85	4.91	4.97	5.03	5.08	5.14
9	5.20	5.26	5.31	5.37	5.42	5.48	5.54	5.60	5.66	5.72

Storage-plants.—These plants consist of a battery of tanks, set firmly upon foundations to prevent the breaking of pipe connections under pulsation, in which gas is stored under high pressure.

These batteries are connected through a system of regulators with the distributing mains, it being good practice, however, where the gas is stored under very high pressure to "step down" from the high-pressure battery to a lower-pressure battery or even a single tank, through the intermediation of a regulator, and from the lower-pressure battery through another regulating system to the mains.

SPECIFICATIONS FOR RECEIVING-TANKS.

For 110 Pounds Working Pressure.

Number of Size.	Diameter, Inches.	Length, Feet	Actual Contents, Cubic Feet (ab't).	Thickness of Shell, Inches	Thickness of Heads, Inches	Weight (about), Pounds.	Diameter of Safety-valve, Inches.	Diameter of Inlet and Discharge Openings, Inches.	Compressor Capacity Receiver is best Adapted for, in Cubic Feet Free Air per Minute.
0	18	6	10	11/64	11/64	350	1	2½	90
00	24	6	18	¼	¼	575	1¼	2½	120
1	30	6	29	¼	⅜	950	1½	[illegible]	150
2	36	6	42	¼	⅜	1000	1½	3½	150 to 200
3	36	8	56	¼	⅜	1350	1½	4	200 to 300
4	42	8	77	¼	⅜	1750	2	4	300 to 500
5	42	10	96	¼	⅜	2000	2	5	500 to 700
6	48	12	150	9/32	7/16	3000	2½	6	700 to 1200
7	54	12	190	5/16	7/16	3300	2½	7	1200 to 2000
7½	60	14	275	⅜	½	5500	2½	8	2000 to 3000
8	66	18	437	7/16	9/16	7500	2½	8	3000 and over
9	24	6	18	¼	⅜	625	1¼	4	These are only furnished horizontal style and are used as water-traps in air lines.
10	36	6	42	¼	⅜	1100	1½	6	

Number of Size.	11	12	13	14	15	16	17	18
Diameter	30 in.	36 in.	36 in.	42 in.	42 in.	48 in.	54 in.	66 in.
Length	6 ft.	6 ft.	8 ft.	8 ft.	10 ft.	12 ft	12 ft.	18 ft.
Thickness of shell, inches.	¼	¼	¼	¼	¼	5/16	5/16	⅜
Thickness of heads, "	⅜	⅜	⅜	⅜	⅜	7/16	7/16	½
Diameter of inlet and outlet flanges, inches	3	3	3½	4	5	[illegible]	7	8
Diam. of safety-valve, in.	1½	1½	1½	2	2	2½	2½	3
Compressor capacity receiver is best adapted for, pounds	150 and less	150 to 200	200 to 300	300 to 500	500 to 700	700 to 1200	1200 to 3000	3000 and above
Weight, about, pounds	800	1150	1400	1900	2100	3200	3600	6000

For 150 Pounds Working Pressure. Tested to 225 Pounds Water Pressure.

11	18	6	10	¼	¼	400	1	2½	135
12	24	6	18	9/32	⅜	725	1¼	2½	180
13	[illegible]	6	29	5/16	⅜	975	1½	3	225
14	36	6	42	11/32	⅜	1300	1½	3½	225 to 300
15	36	8	56	11/32	⅜	1600	1½	4	300 to 450
16	42	8	77	⅜	7/16	2075	2	4	450 to 750
17	42	10	96	⅜	7/16	2550	2	5	750 to 1050
18	48	12	150	7/16	½	4000	2½	6	1050 to 1800
19	54	12	[illegible]	7/16	½	4650	2½	7	1800 to 3000
20	60	14	275	½	9/16	7350	2½	8	3000 to 4500

The connections of the battery and the entire system should be as "flexible" as possible, permitting the use of any unit at any time and the addition of other units to extend the capacity of the plant. There is of course an economical ratio existing between the cost of additional storage capacity and the cost of compression; this must in all instances be determined.

A standard size of tank heretofore adopted by some of the Western companies is a tank 6 feet in diameter by 30 feet long, with reinforced manhole fitted with cover and yoke, reinforced 2-inch outlet and inlet, and reinforced 1-inch drip outlet. The tanks must be placed upon their foundations so as to avoid any possibility of an unequal strain throughout its length, as a leak once started in high-pressure tanks is most difficult of repair. The tanks of the dished-head type are most satisfactory. In the installation the tanks should receive the greatest care.

On the opposite page are given the specifications for a few of the receiving-tanks made by the Bury Compressor Company.

These receivers are provided with manholes and can be furnished to rest vertically or horizontally, the price for either being equal for equal sizes. Companion flanges are regularly supplied.

Made of 60,000 pounds t. s. steel. All longitudinal seams double-riveted. Girth seams single-riveted. Heads dished, both convex. Tested and made tight under 165 pounds water pressure. Warranted safe and tight under 110 pounds working pressure.

The Bury Company recommend the placing of the compressor at a distance not less than 50 feet from the storage-plant.

Absolute Pressure.—To find real or absolute pressure, which is necessary in all formulas concerning gas, steam, or air, unless gage pressure is distinctly specified, atmospheric pressure must be added to gage pressure (usually 14.7 lbs. at sea-level).

RELATIVE CARRYING CAPACITY OF GAS-PIPES.

(NORWALK IRON CO.)

Diameter, Inches.	Comparative Capacity.		Diameter, Inches.	Comparative Capacity.	
	Delivery of Gas.	Area of Section.		Delivery of Gas.	Area of Section.
24	1.0	1.00	4	0.0102	0.0278
12	0.17	0.25	3½	0.0069	0.0212
10	0.10	0.175	3	0.0045	0.0156
8	0.06	0.111	2½	0.002835	0.0108
7	0.04	0.085	2	0.001485	0.0069
6	0.03	0.0625	1½	0.000810	0.0039
5	0.0189	0.0434	1¼	0.000450	0.00272
4½	0.0141	0.0351	1	0.000225	0.00173

TRANSMISSION OF GAS OF 0.55 SPECIFIC GRAVITY THROUGH A PIPE WITH 90° BENDS.

(Nelson W. Perry.)

Inches Pressure.	Cubic Feet Delivered.	Velocity of Flow in Cubic Feet per Second.	Increase of Pressure per Bend, Inches.	Total Increased Pressure for 25 Bends, Inches.	Total Initial Pressure, Inches.
1	12,500	4.0	0.0016	0.04	1.04
2	18,000	6.0	0.0034	0.085	2.085
3	23,000	8.0	0.006	0.1495	3.15
4	25,500	8.8	0.0076	0.189	4.189
5	28,000	9.6	0.0086	0.215	5.215
6	32,000	11.0	0.0113	0.28	6.28
7	34,000	12.0	0.0135	0.34	7.34
8	36,000	12.5	0.0147	0.39	8.39
9	38,500	13.0	0.0158	0.4	9.4
10	40,000	14.0	0.0183	0.46	10.46

HIGH-PRESSURE GAS DELIVERY.

(F. H. Oliphant.)

$$\text{Cubic feet per hour} = 42a\sqrt{\frac{P-p}{l}}.$$

P and p are gage pressures at intake and discharge ends of pipe plus 15 lbs.; l is length in yards; a for different sizes of pipe is:

Diameter Inside.	a	Diameter Inside.	a	Diameter Inside.	Diameter Outside.	a
0.25	0.0317	4	34.1	14.25	15	863
0.50	0.1810	5	60	15.25	16	1025
0.75	0.5012	6	96	17.25	18	1410
1.0	1.0000	8	198	19.25	20	1860
				Riveted or cast-iron pipes		
1.5	2.9300	10	350	20	....	2055
2.0	5.9200	12	556	24	....	3285
2.5	10.3700	16	1160	30	....	5830
3.0	16.5	18	1570	36	....	9330

Flow of Gases in Pipes.—The following notes upon Dr. Pole's formula for the flow of gases in pipes have been made by F. S. Cripps and published in the *Journal of Gas Lighting*. Let

Q=discharge of gas in cubic feet per hour;
d=diameter of pipe in inches;
p=pressure of gas in inches of water;
s=specific gravity of gas, air equalling 1;
l=length of pipe in yards.

$$Q = 1350 d^2 \sqrt{\frac{Pd}{sl}};$$

$$d = \sqrt[5]{\frac{Q^2 sl}{(1350)^2 p}};$$

$$p = \frac{Q^2 sl}{(1350)^2 d^5};$$

$$l = \frac{(1350)^2 d^5 p}{Q^2 s};$$

$$s = \frac{(1350)^2 d^5 p}{Q^2 l}.$$

From the above it is apparent that, other things being equal—

Q varies directly as $\sqrt{p}$	p varies directly as Q^2
" " " $\sqrt{d^5}$	" " " l
" inversely as $\sqrt{l}$	" " " s
" " " $\sqrt{s}$	" inversely as d^5
d varies directly as $\sqrt[5]{Q^2}$	l varies directly as p
" " " $\sqrt[5]{l}$	" " " d^5
" " " $\sqrt[5]{s}$	" inversely as Q^2
" inversely as $\sqrt[5]{p}$	" " " s

s varies directly as p
" " " d^5
" inversely as Q^2
" " " l

A consideration of the foregoing gives rise to the following axioms or rules:

QUANTITY—PRESSURE.

Double the quantity requires four times the pressure.
Or, four times the pressure will pass double the quantity.
Half the quantity requires one fourth the pressure.
Or, one fourth the pressure is sufficient for half the quantity.

QUANTITY—LENGTH.

Double the quantity can be discharged through one fourth the length.

Or, one fourth the length will allow of double the discharge.

Half the quantity can be discharged through four times the length.

Or, four times the length reduces the discharge one half.

QUANTITY—DIAMETER.

Thirty-two times the quantity requires a pipe four times the diameter.

Or, a pipe four times the diameter will pass thirty-two times as much gas.

A pipe one fourth the diameter will pass one thirty-second of the quantity.

Or, one thirty-second of the quantity can be passed by a pipe one fourth the diameter.

QUANTITY—SPECIFIC GRAVITY.

The specific gravity stands in just the same relation to the volume as the length does (see Axioms 3 and 4).

PRESSURE—LENGTH.

If the pressure is doubled the length may be doubled.

And, conversely, if the length be doubled the pressure must be doubled.

If the pressure be halved the length may be halved.

And, conversely, if the length be halved the pressure must be halved.

From Axioms 8 and 9 it is evident that—

The pressure required to pass a given quantity of gas varies exactly as the length of the pipe.

PRESSURE—SPECIFIC GRAVITY.

The pressure required to pass a given quantity of gas also varies exactly as the specific gravity of the gas. Hence if the specific gravity of the gas were doubled, double the pressure would be required.

PRESSURE—DIAMETER.

One thirty-second part of the pressure is sufficient if the diameter be doubled; or, in other words, if you double the diameter you require only one thirty-second of the pressure to pass the same quantity of gas.

If you halve the diameter, thirty-two times the pressure is required.

And, conversely, if you increase the pressure thirty-two times, the diameter can be halved.

LENGTH—DIAMETER.

The length can be increased thirty-two times if the diameter be doubled.

And, conversely, if the diameter be doubled, the length can be increased thirty-two times and pass the same quantity of gas.

If the diameter be halved, the length must be reduced to one thirty-second to pass the same quantity of gas.

And, conversely, if the length be made one thirty-second of the distance, the diameter may be halved.

SPECIFIC GRAVITY—LENGTH.

If the specific gravity be doubled, the length must be halved, and vice versa, to satisfy the equation.

SPECIFIC GRAVITY—DIAMETER.

The specific gravity follows the same laws as the length docs in relation to the diameter.

It must be borne in mind, when using the above rules, that all other conditions remain the same when considering the effect of one factor on another in the different pairs.

The above may be found convenient for rule-of-thumb calculations.

COMPARISON OF FORMULÆ.

Mr. Oliphant has checked certain formulæ on delivering natural gas 100 miles into a gas-holder through 8-inch pipe.

Taking the Newton conditions and using the several formulæ we obtain the following results:

Formula.	Calculated Cu. Ft. per Hour.
(Actual volume delivered)	(18,200)
Pittsburg	18,380
Cox's	16,000
Oliphant's	16,260
" corrected	17,510
Robinson's	18,730
Unwin's	31,870
Velde's	22 060
Richards' (corrected for 0.6—g gas)	18,708
Hiscox's (corrected for 0.6—g gas)	16,250
Lowe's	26,910

CHAPTER XVII.

HOUSE PIPING.

SPECIFICATIONS FOR HOUSE PIPING.

FIRST. The piping must stand a pressure of 3 lbs. per square inch, or 6 in. of mercury column, without showing any drop in the mercury column of the gage for a period of ten minutes. After the fixtures are in place, the piping and fixtures must stand the same test. However, when on third inspection there are any old fixtures under test, the pressure required will be only 8 in. of water column. Leaky fittings or pipe must be removed; cement-patched material will be rejected.

Second. The sizes of pipe shall not be less than are called for in the table shown on page 240. This table shows for any given number of outlets the greatest length allowed for each size of pipe.

Third. The piping must be free from obstructions. Every piece of pipe should be stood on end and thoroughly hammered and blown through before being connected. Use white lead or other jointing material sparingly, to avoid clogging the pipe. Always put jointing material on the male thread on end of pipe, and *not in the fitting*. The use of gas-fitters' cement is prohibited. All piping should be blown through after being connected, to make sure it is clear.

Fourth. All piping must be free from traps. All pipes shall grade back toward the riser, and thence to the meter; use a spirit-level in grading. Any pipe laid in a cold or damp place should be properly dripped and protected.

Fifth. The piping must be rigidly supported by hooks and straps. Outlets for brackets or drops must be secured by straps or flanges, which are nailed or screwed to the woodwork. Where the walls are not masonry, they should be plugged and the straps fastened to the plugs.

Sixth. The riser must extend to a point within 24 in. of the proposed location of the meter, and, if a horizontal line is needed,

e, with plug looking down, must be put on the bottom of the ical pipe. In piping new houses the gas-fitter should decide re the gas-meter ought to be located, and extend the riser to inate within 24 in. of this point. In determining the proper ion of the meter, he should be guided by the following:

ieters.—Meters must not be located under stoops, sidewalks, iow-windows, near furnaces or ovens, locked in compart-, nor placed in any other situation where they will be inac-le or liable to injury.

the building is on a street corner, the company should be from which street the service will be run, and where the should be located. If at any time the fitter is in doubt as future location of a meter, on application to the proper , some one will be sent to instruct him.

Where more than one meter is desired in a given building, to accommodate different tenants, the company will set as many meters as there are separate consumers, connecting them to one service-pipe, provided that the risers or pipes leading to the different tenants are extended to within a reasonable distance (say 6 ft.) of the actual or proposed location of service. All the meters must stand side by side in the cellar or basement, within view of the end of the service. The company will not set meters on the different floors of a building. Risers must not be scattered, but must drop together to the cellar or basement, preferably in front part of building. They should not extend more than 3 in. below bottom of joists, and should be kept at least 3 in. apart. They must never end in such a place that beams, girders, heater-pipes, etc., to be put up subsequently, would prevent making connections to the meter.

Always use fittings in making turns; do not bend pipe. Do not use unions in concealed work; use long screws or right and left couplings. Long runs of approximately horizontal pipe must be firmly supported at short intervals to prevent sagging. All horizontal outlet-pipes must be taken from the sides or tops of running lines, never from below.

All ceiling outlets must project not more than 2 in. nor less than $\frac{3}{8}$ in., and must be firmly secured and perfectly plumb. Side-wall outlets must project not more than $\frac{3}{8}$ in., and must be at right angles to the wall and be firmly secured.

Where pipes pass through masonry walls they must be encased, the gas-pipe resting on the bottom of the casing-pipe with a clearance of half an inch on top.

Pipes must be so run and covered as to be readily accessible. Do not run them at the bottom of floor-beams which are to be lathed and plastered. They must be securely attached to the top

of the beams, which should be cut out as little as possible. Where pipes are paralleled to beams, they must be supported by strips nailed between two beams. These strips must be not over 4 ft. apart. All cutting of beams should be done as near as possible to the ends or supports of the beams. Pipes must not be laid beneath tiled or parquet floors, under marble platforms, or under hearthstones, where it can be avoided. Floor-boards over pipes should be fastened down by screws, so that they can readily be removed.

No stove line must be used for lighting purposes without first obtaining permission from the company.

Requirements for Gas-fixtures.—1. All fixtures for outside lighting must be made so that at all traps there is provision for letting out condensation.

2. Pendants must be made as follows:

	Length of Pendant Over All.	When Made of	
		Iron Pipe, in. diam.	Brass Pipe, in. diam.
One-piece pendants...	2 ft. 9 in. and under......	$\frac{1}{8}$	$\frac{3}{8}$
	Over 2 ft. 9 in...........	$\frac{1}{4}$	$\frac{7}{16}$
Harp or "C" pendants..	Any length.............	$\frac{1}{4}$	$\frac{3}{8}$

Length of pendant over all is understood to be the distance in a straight line from the stiff joint to the lowest part of the pendant.

3. Arms of gas-fixtures, or those parts which carry the gas from only one burner-nozzle, must be of the following sizes:

Length of Arms.	When Made of		
	Iron Pipe.		Brass Pipe, in. diam.
	Cased, in. diam.	Uncased, in. diam.	
12 in. or shorter........................	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{3}{8}$
From 12 in. to 18 in. inclusive.............	$\frac{1}{8}$	$\frac{1}{4}$	$\frac{7}{16}$
Over 18 in..............................	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{2}$

Length of arm is understood to be the distance in a straight line from the center of the stem to the center of the burner.

4. Stems of 2-light straight or toilet pendants must be made as follows:

Length of Pendant Over All.	When Made of Iron Pipe.	
	Cased, in. diam.	Uncased, in. diam.
2 ft. 6 in. and under.	$\frac{1}{8}$	$\frac{1}{4}$
Over 2 ft. 6 in. and under 3 ft. 6 in.	$\frac{1}{4}$	$\frac{1}{4}$
3 ft. 6 in. and over.	$\frac{1}{4}$	$\frac{3}{8}$

5. Stems of gas-fixtures, or those parts which carry gas for more than one burner-nozzle, must be the following sizes:

Number of Lights.	When Made of	
	Iron Pipe, cased.	Brass Pipe.
6 or under.	Not smaller than $\frac{1}{4}$ in.	Not smaller than $\frac{1}{2}$ in.
7 to 12 inclusive.	Not smaller than $\frac{3}{8}$ in.	Not smaller than $\frac{1}{2}$ in.
12 and over.	$\frac{1}{2}$ in. and over.	

6. All keys must be well ground, and so fitted as to show no leak under 3 lbs., mercury-gage pressure, when the keys can be turned by finger.

7. The opening in all globe rings must be a snug fit against the burner-nozzle, and must flare out in an inverted-cone shape, so that the burner, in screwing down, will not strike the knife-edge of the flare, but hold the globe ring tight by binding against the sides of the cone, making at the same time a tight joint with the nozzle-threads.

8. The company reserves the right to take fixtures apart at any time, and to refuse to pass them if they are not constructed in accordance with good workmanship.

Note.—The above requirements refer to combination fixtures as well as to plain gas-fixtures. Where there are good reasons for making the stems of combination fixtures supplying less than six lights of smaller size than $\frac{1}{4}$-in. pipe, the matter should be taken up with the company by the fixture manufacturer.

The following table is based on the well-known formula for the flow of gas through pipes. The friction, and therefore the pressure necessary to overcome the friction, increases with the quantity of gas that goes through, and as the aim of the table is to have the loss in pressure not exceed one-tenth of an inch water pressure in 30 ft., the size of the pipe increases in going from an extremity toward the meter, as each section has an increasing number of outlets to supply. The quantity of gas the piping may be called on to pass

through is stated in terms of ⅜-in. outlets, instead of cubic feet, outlets being used as a unit instead of burners, because at the time of first inspection the number of burners may not be definitely determined. In designing the table, each ⅜-in. outlet was assumed as requiring a supply of 10 cu. ft. per hour.

TABLE SHOWING THE CORRECT SIZES OF HOUSE PIPES FOR DIFFERENT LENGTHS OF PIPES AND NUMBERS OF OUTLETS.

No. of Outlets.	Length of Pipe in Feet for Various Diameters.								
	⅜ in.	½ in.	¾ in.	1 in.	1¼ in.	1½ in.	2 in.	2½ in.	3 in.
1	20	30	50	70	100	150	200	300	400
2	......	27	50	70	100	150	200	300	400
3	......	12	50	70	100	150	200	300	400
4	......	......	50	70	100	150	200	300	400
5	......	......	33	70	100	150	200	300	400
6	......	......	24	70	100	150	200	300	400
8	......	......	13	50	100	150	200	300	400
10	......	......	......	35	100	150	200	300	400
13	......	......	......	21	60	150	200	300	400
15	......	......	......	16	45	120	200	300	400
20	......	......	......	......	27	65	200	300	400
25	......	......	......	......	17	42	175	300	400
30	......	......	......	......	12	30	120	300	400
35	......	......	......	......	......	22	90	270	400
40	......	......	......	......	......	17	70	210	400
45	......	......	......	......	......	13	55	165	400
50	......	......	......	......	......	......	45	135	330
65	......	......	......	......	......	......	27	80	200
75	......	......	......	......	......	......	20	60	150
100	......	......	......	......	......	......	......	33	80
125	......	......	......	......	......	......	......	22	50
150	......	......	......	......	......	......	......	15	35
175	......	......	......	......	......	......	......	......	28
200	......	......	......	......	......	......	......	......	21
225	......	......	......	......	......	......	......	......	17
250	......	......	......	......	......	......	......	......	14

In using the table observe the following rules:

1. No house riser shall be less than ¾ in. The house riser is considered to extend from the cellar to the ceiling of the first floor. Above the ceiling the pipe must be extended of the same size as the riser until the first branch line is taken off.

2. No house pipe shall be less than ⅜ in. An extension to existing piping may be made of ¼-in. pipe to supply not more than one outlet, provided said pipe is not over 6 ft. long.

3. No gas-range shall be connected with a smaller pipe than 1 in. No pipe laid underground shall be smaller than 1¼ in. No

pipe extending outside of the main wall of a building shall be less than ¾ in.

4. In figuring out the size of pipe, always start at the extremities of the system and work towards the meter.

5. In using the table, the lengths of pipe to be used in each case are the lengths measured from one branch or point of junction to another, disregarding elbows or turns. Such lengths will be hereafter spoken of as "sections," and are ordinarily of but one size of pipe, as no change in size of pipe may be made other than at branches or outlets, except where the length of a "section" is greater than the greatest length allowed in the table for the size of pipe required by the outlets supplied by the "section." For example, if a section supplying two outlets is 33 ft. long, 27 ft. of this could be ½ in. and the remaining 6 ft. of ¾ in.

6. If any outlet is larger than ⅜ in., it must be counted as more than one, in accordance with the schedule below:

Size outlet; diam. inches......	½	¾	1	1¼	1½	2	2½	3
Outlets in table..............	2	4	7	11	16	28	44	64

Gas-grates count as follows: a 24×30-in. for four outlets, and a 30×30-in. for six outlets. Gas-logs count as one outlet for every 2 in. in length; thus a 24-in. log counts as twelve outlets.

7. If the exact number of outlets given cannot be found in the table, take the next larger number. For example, if seventeen outlets are required, work with the next larger number in the table, which is twenty.

8. For any given number of outlets do not use a smaller-sized pipe than the smallest size that contains a figure in the table for that number of outlets. Thus to feed fifteen outlets no smaller pipe than 1 in. may be used, no matter how short the "section" may be.

9. Never supply gas from a smaller size of pipe to a larger one. If we have 25 outlets to be supplied through 300 feet of pipe, and these 25 and 5 more, making 30 in all, through 100 feet of pipe, we should find by the table that 30 outlets through 100 feet would require 2-inch piping; but as under this condition a 2-inch pipe would be supplying a 2½-inch, the 100-foot section must be made 2½ inches. This does not apply to the case of a small pipe inside of a building supplying one outside of the main wall of a building made large on account of the conditions of outside supply.

PIPE-FITTING SPECIFICATIONS.

In all cases of repair of leaks a notice giving the location and extent of all work performed shall be filed with the building commissioner immediately upon completion of the same.

No pipe or fitting shall be covered or concealed from view until approved by one of the gas-fitting inspectors of the building department, or for thirty hours after notice has been given to the building commissioner.

Pipes shall be run and laid to avoid any strain or weight on the same, except that of the fixtures.

Outlets for fixtures shall be securely fastened: all outlets not covered by fixtures shall be left capped, and the number of burners for each outlet shall be marked on the builders' plan.

Pipes laid in a cold or damp place shall be properly dripped, painted with two coats of red lead and boiled oil, or covered with felting satisfactory to the building commissioner.

Swing-brackets shall have a globe or guard to prevent their burner from coming in contact with the wall. Bracket outlets shall be at least 2½ inches from window or door casings.

Stop-pins to cocks shall be screwed into place.

The use of gas-fitters' cement is prohibited absolutely.

Inside services shall be tested by the fitter who received the permit to connect the service or meter.

There shall be a final test by a gas-fitter of all fixtures and pipes by a column of mercury raised not less than six inches, which must stand ten minutes; this test to be made in the presence of one of the gas-fitting inspectors of the building department; the gage to be made of glass tubing of uniform interior diameter, and so constructed that both surfaces of the mercury will be exposed.

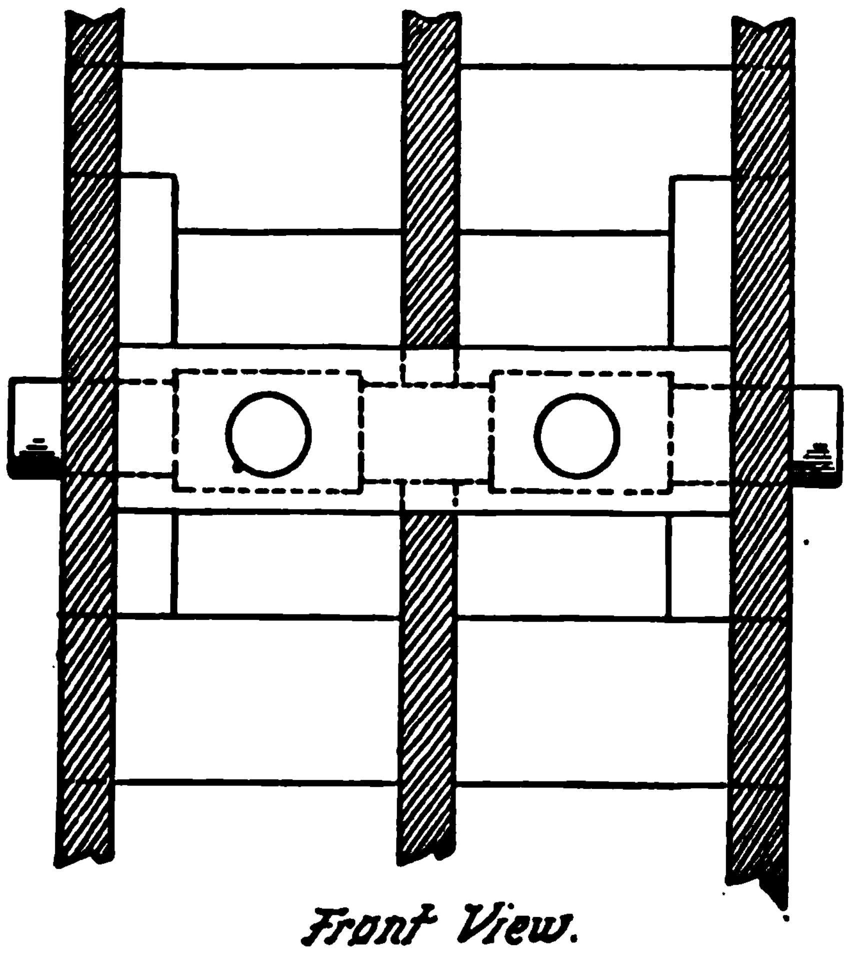
All gas-pipes shall be of wrought iron or steel, all fittings of malleable iron, and all meter connections of lead pipe of the same size as the riser, except where meters are to be connected with flanges.

Brass solder nipples shall be used on all lead-meter connections.

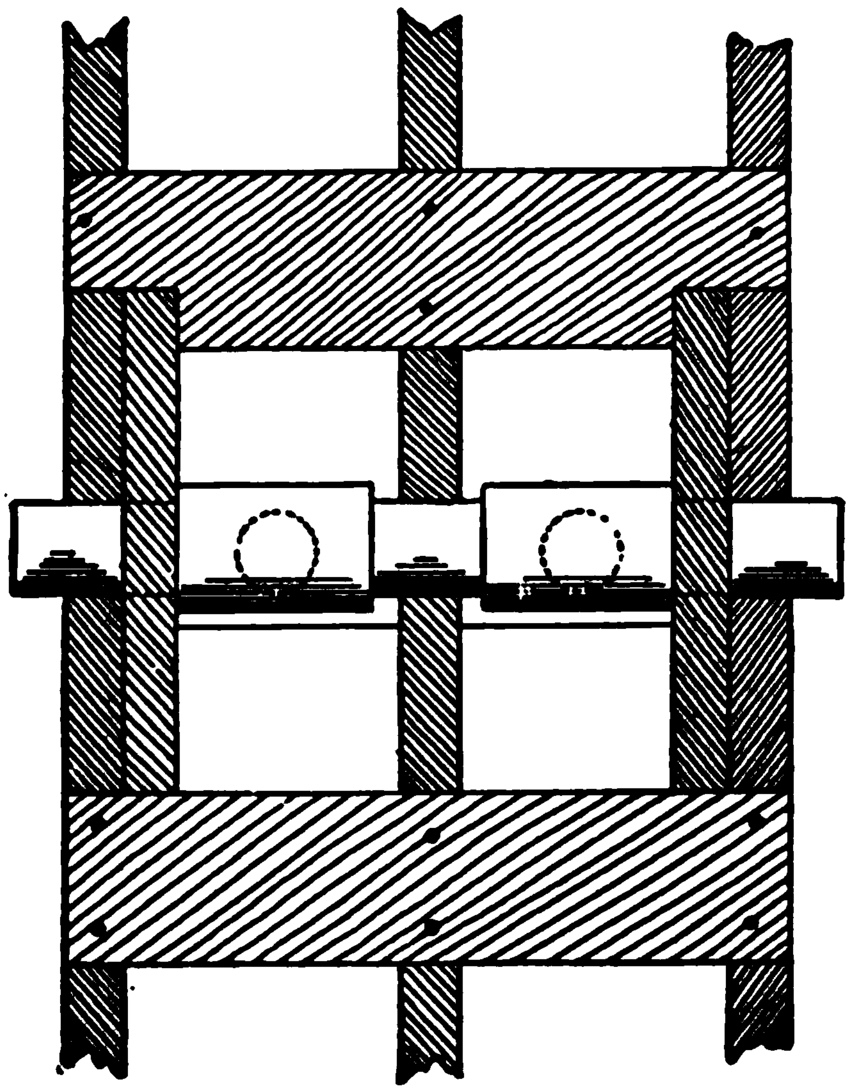
Gas-pipes of iron shall be run in accordance with the following scale:

Diameter, Inches.	Length, Feet.	No. of Burners.
⅜	26	3
½	30	6
¾	50	20
1	70	35
1¼	100	60
1½	150	100
2	200	200
2½	300	300
3	450	450
3½	500	600
4	600	750

Gas Pipe in Breastwork.



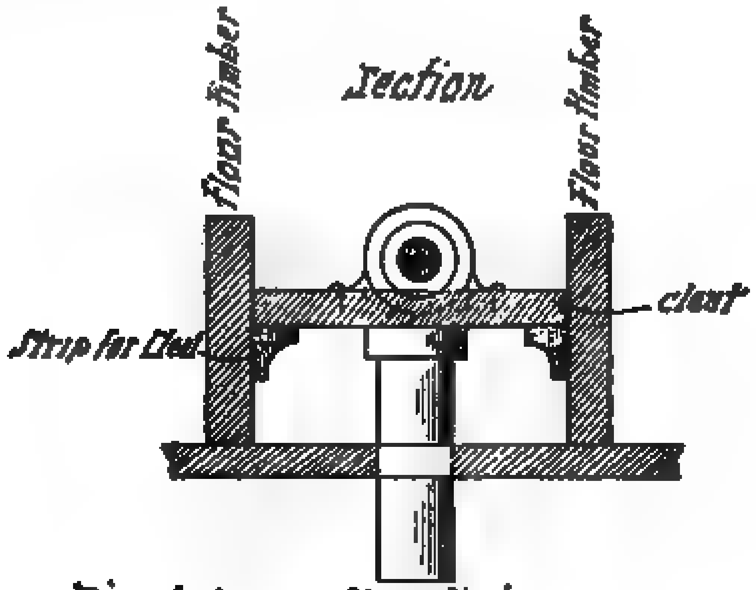
Front View.



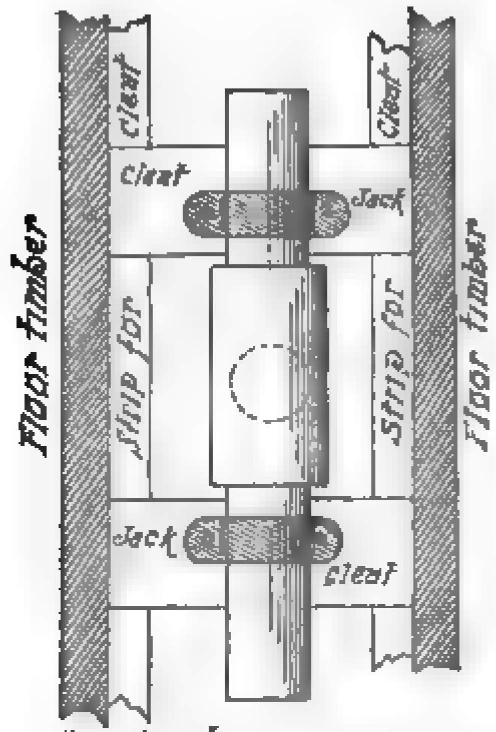
Back View.

When brass piping is used on the outside of plastering or woodwork, it shall be classed as fixtures.

Outlets and risers not provided with fixtures shall be properly capped.



Pipe between floor timbers, pipe running in same direction.



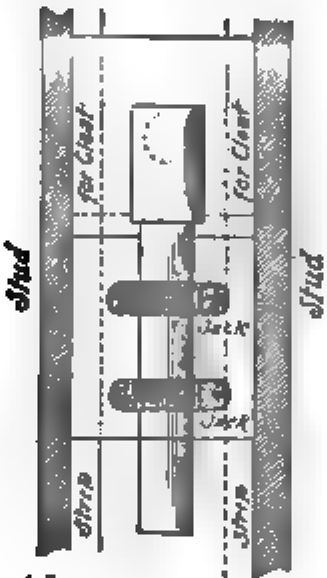
Plan looking down on pipe running in same direction as floor timbers

Outlets for fixtures shall not be placed under tanks, back of doors, or within three feet of any meter.

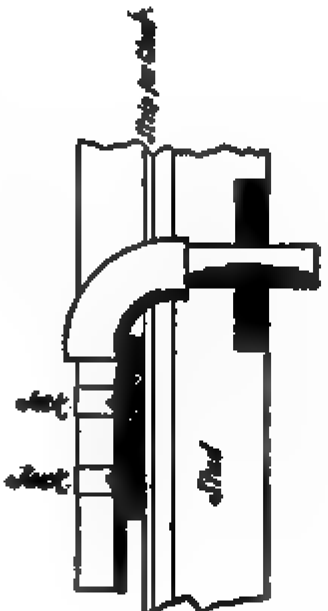
Gas-burners less than two feet from a plastered ceiling, or less than three feet from overhead woodwork, shall be protected by a

shield satisfactory to the building commissioner. In first-class buildings no shields will be required.

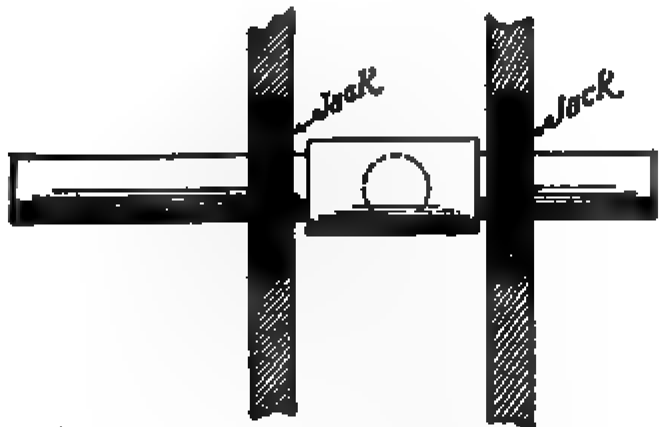
Brass tubing used for arms or fixtures shall be at least No. 18 standard gage, with full thread. All threads shall screw in at least



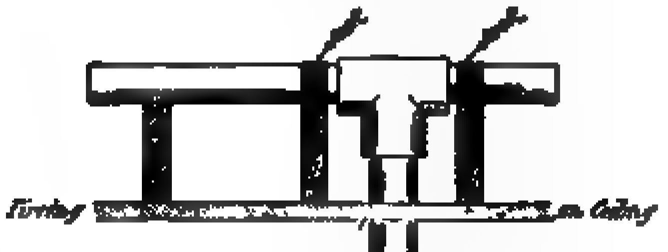
View from Back of Partition



Pipe in Partition. Section



Plan showing pipe over timbers - looking down -



Pipe over timbers Section.

$\frac{3}{16}$ of an inch. Rope or square tubing shall be brazed or soldered into fittings and distributors, or have a nipple brazed into the tubing.

Cast fittings such as cocks, swing-joints, double centers, and nozzles shall be standard fittings, except for factory use, where

extra-heavy or mill fittings shall be used. The plugs of all cocks must be ground to a smooth and true surface for their entire length, be free from sand-holes, have not less than $\frac{3}{4}$-inch bearing on cast fittings and $\frac{11}{16}$ of an inch on turned fittings, have two flat sides on the end for the washer, and have two nuts instead of a tail-screw. Stems of fixtures of two lights or more each shall be not less than $\frac{1}{4}$ of an inch iron-pipe size. L-burner cocks shall not be used at the end of chandelier arms except in stores, churches, theaters, halls, and places of assembly or public resort.

Outlets for gas-ranges shall have a diameter not less than one inch, and all gas-ranges and heaters shall have a cock on the service-pipe. Ranges and heaters must be connected with right and left couplings, except in fireplace work, where brass unions may be used.

Pipes shall be laid above timbers, unless otherwise permitted by the building commissioner.

No second-hand pipe shall be put into use in any building without the written permission of the building commissioner.

Drops or outlets less than $\frac{3}{4}$ of an inch in diameter shall not be left more than $\frac{3}{4}$ of an inch below plastering, center-piece, or woodwork, and other outlets shall not project more than $\frac{3}{4}$ of an inch beyond plastering or woodwork.

Fastening-boards shall not be cut away to accommodate electric wires. All outlets shall be fastened according to the diagrams on page 245.

Gas-pipes, arms, and stem of fixtures shall be of the kind classed as standard pipe, and shall weigh according to the following table:

Diam. of Pipe, Inch.	Pounds per Foot.
$\frac{1}{8}$	0.24
$\frac{1}{4}$	0.42
$\frac{3}{8}$	0.56
$\frac{1}{2}$	0.85
$\frac{3}{4}$	1.12
1	1.67
$1\frac{1}{4}$	2.24
$1\frac{1}{2}$	2.68
2	3.61
$2\frac{1}{2}$	5.74
3	7.54
$3\frac{1}{2}$	9.00
4	10.66

No gas-pipe shall be laid within six inches of an electric wire, except where the electric wire is an insulated conduit.

Wherever spark-lighting or self-lighting burners are used the mercury test shall be applied to the cocks.

GAS-ENGINES.

(a) Gas-engines must be connected to service from which no gas for illuminating purposes is used.

(b) Exhaust-pipes shall be run to roof when possible, not come in contact with woodwork, and be properly protected.

(c) Diaphragms and bags must be on the same floor with engine and have a valve governing same.

(d) The sizes of pipes used in connecting gas-engines will be as follows:

Horse-power.	Feet per Hour.	Burners	Diam., Inches	Length, Feet.	Horse-Power.	Feet per Hour.	Burners	Diam., Inches.	Length, Feet.
1	40	10	3/4	50	15	600	150	2	200
2	80	20	3/4	50	16	640	160	2	200
3	120	30	1	70	17	680	170	2	[illegible]
4	160	40	1 1/4	100	18	720	180	2	[illegible]
5	200	50	1 1/4	100	19	760	190	2	200
6	240	[illegible]	1 1/4	100	20	800	200	2	[illegible]
7	280	70	1 1/2	150	21	840	210	2 1/2	300
8	320	[illegible]	1 1/2	150	22	880	220	2 1/2	300
9	360	90	1 1/2	150	23	920	230	2 1/2	[illegible]
10	400	100	1 1/2	150	24	960	240	2 1/2	300
11	440	110	2	200	25	[illegible]	260	2 1/2	300
12	480	120	2	200	26	1040	260	2 1/2	300
13	520	130	2	200	27	1080	270	2 1/2	300
14	560	140	2	200					

Gas shall not be turned on in any building until the piping and fixtures have been approved by the building commissioner.

Capacity of House Piping.—The following is given in the report of the committee on research of the American Gaslight Association:

Diameter, Inches.	Length Allowed, Feet.	No. of Burners.
3/8	20	[illegible]
1/2	30	6
3/4	50	20
1	70	[illegible]
1 1/4	100	60
1 1/2	[illegible]	100
2	200	200
2 1/2	300	300
3	[illegible]	450

Allowing six feet of gas per hour to a burner, this table seems to be figured for gas of a gravity of 0.42 and a loss of pressure of 0.1

in. within thirty feet. The following will show the capacity of pipes of the length and diameter given in the foregoing for gas having a specific gravity of 0.42, 0.55, and 0.68, the loss of head in each case being 0.1 inch in 30 feet.

TABLE SHOWING AMOUNT OF GAS THAT WILL BE DELIVERED IN ONE HOUR THROUGH PIPE OF GIVEN SIZE AND LENGTH WITH A LOSS OF PRESSURE OF ONE INCH OF WATER IN THREE HUNDRED FEET.

Specific gravity of gas	....	0.42	0.55	0.68
Diameter in Inches.	Length in Feet.	Cubic Feet per Hour.	Cubic Feet per Hour.	Cubic Feet per Hour.
3/8	20	18	15.6	14
1/2	30	37	32.2	29
3/4	50	101	88	80
1	70	210	180	162
1 1/4	100	360	310	280
1 1/2	150	577	500	450
2	200	1200	1030	930
2 1/2	300	2050	1800	1610
3	450	3300	2850	2560

Pipe Cement.—The following "dopes" are in common use for the making up of threaded pipes and fittings:

Where oil or gas or vapors are used under pressure, the best mixture is equal parts of white lead, red lead, coach-varnish, and dryer. Under ordinary conditions there may be used either:

Red lead and graphite, mixed with water and oil.

Graphite and lard-oil.

Raw linseed-oil (1/3) and Portland cement (2/3 by volume).

Asphaltum and varnish.

Plumbago and linseed-oil.

Fine emery and white lead.

Aluminum elastic cement and linseed-oil.

One part each of litharge, red lead, and white lead, mixed with linseed-oil.

Shellac and wood-alcohol.

Cylinder-oil and graphite.

White lead and coal-tar.

FLUXES FOR SOLDERING.

Iron to steel: Borax and sal-ammoniac.

Tinned iron: Rosin and zinc chloride.

Copper and brass: Sal-ammoniac and zinc chloride.

Lead and composition pipe: Rosin and sweet-oil.

Zinc: Zinc chloride.

CHAPTER XVIII.

APPLIANCES.

A. GAS RANGES AND HEATERS.

A GAS-RANGE having four top burners and an oven-burner should never be connected to less than a $\frac{3}{4}$-in. supply-pipe. If the run is long (see Rules for House Piping), a 1-in. pipe is better, say for a distance of over 50 ft. from the meter. A 1-in. pipe is, however, better practice, as this admits the connection of a supply-pipe for a water-heater. The meter should not be smaller than a 5-light. The maximum capacity of a range of this character is supposed to be about 60 cu. ft. per hour.

Efficiency.—The following is given by the gas education trustees of the American Gaslight Association as a comparative test of the efficiency of gas-ranges. The comparative efficiency of the top burners of various samples of gas-stoves may be tested by determining the length of time and the amount of gas required to heat a definite quantity of water from the temperature of, say, 60° F. to the boiling-point. The same kettle should be used throughout the test, and the weight of water employed, its temperature at the start, the exact time at which it begins to boil, and the amount of gas consumed being accurately determined in each case.

The efficiency of the oven may be tested by determining the time and amount of gas required to bring each oven up to a baking heat, to be determined with an oven thermometer, and then to bake a definite weight of either bread or biscuit. The dough must be ready to put into the oven as soon as the required heat is attained, so that no gas is wasted while waiting for the dough to be gotten ready, since any delay of this kind would spoil the test. Each oven should also be tested for evenness of distribution of the heat throughout its whole interior. This can be done by placing pieces of white writing-paper (unglazed) in different parts of the oven and noticing the extent to which the different pieces are browned when the oven is hot enough to bake. The more nearly they approach the same

color the more uniform is the distribution of heat throughout the oven and the better will it bake. As a rule, the ovens that show good efficiency by the baking test will also show a uniform distribution of the heat.

Burners.—Atmospheric burners in stoves may be classed in the main as ring burners with drilled holes, radial or star burners with drilled holes, ring burners with slits sawed in them, and star burners with sawed slits. Annular slit-ring burners and serrated disk or cap burners are occasionally found, but the drilled or sawed burners are most commonly used in the best type of stoves. Other things being equal, such as the same gas and air mixture, shape and weight of metal, etc., the drilled-ring burners are much more efficient than the ring-burners with slits and are moreover freer from stoppage and easier to clean. Next to the drilled-ring burners come the drilled radial burners, after which follow the sawed ring and sawed radial, their sequence showing the order of efficiency.

The advantage possessed by the ring burners is evident to the writer because of a certain amount of regenerative heat and also a more equal flow of air to support combustion. By regenerative heat is meant that a certain amount of the radiant heat of the burner is utilized in bringing up the gas to the point of combustion prior to ignition and thereby permitting less gas to pass the flame area consumed.

Great care should be taken in the proper adjustment of air-mixers, the best test of which is the color (an electric blue) of the flame issuing from the burner. A lack of sufficient air will enormously reduce the economy and efficiency of the burners, besides causing the burner to clog up and flash back.

This flashing back is caused, as a rule, either by improper design of the burner, a preponderance of gas, or insufficient air, due either to bad regulation or stoppage. In many Bunsen burners, brass gauze, or netting, is used, both to promote the more intimate union of the gas and air and, through radiation, to lower the temperature of the gas below the point of ignition prior to its exit from the burner. This gauze, or netting, occasionally becomes foul and, by its failure to supply sufficient air or by the increase of heat due to its failure to radiate on account of this insulation, causes flashing back and premature explosion.

In an ordinary atmospheric burner the quantity of air in the mixture generally depends upon two conditions: first, the size of the air-inlet, and second, the velocity of the gas, which draws in the air by an aspirator action. It is, therefore, an absolute necessity in all conditions where atmospheric burners or Bunsen mixtures are used to have an ample gas pressure, the efficiency of the burner increasing to some measure in direct ratio to the initial

pressure. Incandescent mantles, which are in reality devices to convert radiant into luminous energy, are good examples of this principle.

FLOW OF GAS IN CUBIC FEET PER HOUR THROUGH THIN ORIFICES, SUCH AS AIR-MIXERS, FOR GAS-STOVES.

Pressure Equivalents.			Diameter of Orifices, Inches.					
Ounces per Sq. In.	Tenths of Inches of Water-head.	Tenths of Inches of Mercury Column.	$\frac{5}{64}$	$\frac{3}{32}$	$\frac{7}{64}$	$\frac{4}{32}$	$\frac{5}{32}$	$\frac{6}{32}$
			Cubic Feet Discharged per Hour.					
....	8	0.59	8.0	12.0	15	20	30	45
....	10	0.74	9.0	13.0	17	23	34	51
....	12	0.89	10.0	15.0	18	25	36	56
0.8	13.6	1.00	10.8	16.0	20	27	40	61
....	14	1.03	11.3	17.0	21	28	42	63
....	16	1.18	11.6	17.5	21.5	29	43	65
....	18	1.34	12.0	18.0	22	30	44	67
....	20	1.48	12.8	19.0	23	32	46	72
....	25	1.86	13.5	20.4	25	34	50	76
1.6	27	2.00	15.9	21.0	27	38	54	86
1.8	30	2.02	16.4	24.5	31	41	62	92
2.4	41	3	18.0	27.5	34	46	68	105
3.2	54	4	21.6	32.0	41	54	82	122
4.0	68	5	24.0	35.5	46	60	92	135
4.8	81	6	26.4	39.5	51	66	102	148
5.6	65	7	28.4	42.5	54	71	108	160
6.4	109	8	30.0	45.0	57	75	114	169
7.2	122	9	31.0	47.0	61	78	122	176
8.0	137	10	32.4	48.5	64	81	128	182
8.8	150	11	33.0	51.0	68	85	138	191
9.6	163	12	37.2	55.0	71	93	142	209
10.4	177	13	38.8	58.0	74	97	148	218
11.2	190	14	40.4	60.5	77	101	154	227
12.0	204	15	42.0	63.0	80	105	160	236
12.8	218	16	43.0	65.0	82	108	164	243
13.6	231	17	44.0	66.0	84	110	168	247
14.4	245	18	45.6	67.0	87	114	174	255
15.2	258	19	47.0	70.0	90	117	180	263
16.0	274	20	48.0	72.0	92	120	184	270

Piping.—The gas-range having 4 top burners and an oven-burner should never be connected to the meter by less than a $\frac{3}{4}$-in. pipe and this should only be in instances where the run is 50 ft. or under, 1-in. pipe being used for a greater distance. This calculation, based on gas having a specific gravity of 0.7, would show a loss in pressure of about 0.1 in., which, under average conditions, should be the maximum loss advisable.

A gas-range of the average type should invariably be connected to a 5-light meter, a 3-light meter, while under most conditions having the capacity for the passage of the requisite gas, entailing too great a loss of pressure. The author's tests show that a loss of pressure through a 3-light meter due to maximum demand of gas-range averages 0.4 in.

Heat Insulation.—The consensus of opinion seems to be that the asbestos heat insulating lining supplies greater economy than the dead air-space of gas-ranges, although this would probably not be true theoretically. In practice the dead air-space is impossible of realization and the practical loss of radiant heat is greater; moreover, the asbestos-lined oven seems to have its heat more evenly distributed. The following table, compiled by Prof. C. L. Norton, shows the protection afforded by insulating linings:

A steam-pipe heated to 385° F. shows an outside temperature of

356°	covered	with	asbestos-paper	$\frac{1}{64}$	in.	thick.
229°	"	"	"	"	$\frac{1}{32}$	"	"
302°	"	"	"	"	$\frac{1}{16}$	"	"
266°	"	"	"	"	$\frac{1}{8}$	"	"

J. C. Bertsch is authority for the statement that the transmission of heat per square foot of surface per minute through a dead air-space 1 in. in thickness is 8 B.t.u., while that of asbestos-paper 1 in. thick is 3½ B.t.u. He moreover states that the dead air-space, properly speaking, does not exist in the oven of the modern gas-range, it being impossible to join the metal sheets so closely as to prevent circulation; under these conditions air has little or no properties insulating value. Therefore asbestos-boards $\frac{1}{16}$ to $\frac{1}{8}$ in. in thickness are the more effective and economical and moreover tend to form a dead air-space with the outside metal sheet.

What is commonly known as sweating in the oven of a gas-range is largely due to the hydrogen in the gas burning to aqueous vapor and being condensed against the walls of the oven. It may be the result of improper ventilation, which may be remedied by the rather uneconomical expedient of increasing the size of the flue-outlet; or the air-passage may have become closed and steam from any article being cooked may itself have been condensed; it may also be caused by the cold walls of the oven, due to improper lining, in which case the lining should be examined and replaced. The ventilation may be responsible, as before suggested, by reason of the insufficient draught, the air-ports in the range having become stopped and failing to carry off the aqueous vapor formed by the combustion of gas. In many instances, however,

it is simply the shock of the first gases of combustion coming in contact with the cold sides of the range, and this can be overcome by allowing a more lengthy burning of the pilot-light, or by leaving the oven-doors open for a minute or so after lighting the range. At this point it may also be stated that ranges when not in use for any length of time should be left with their doors partly open, or, better still, unhinged and entirely removed, as the metal of the range has a tendency to condense upon itself moisture from the atmosphere, which in a closed oven is most destructive to the sheets and linings.

Gas Consumed.—The consumption of gas-range ovens varies naturally with the dimensions of the oven. With 650 to 700 B.t.u. gas and 2-in. water pressure the burners should be able to deliver 45 cu. ft. of gas per hour to a 16-in. oven and 50 cu. ft. with an 18-in. oven (double burner). Under average burning conditions the oven can doubtless be heated with a less quantity of gas, but a certain latitude in heating power should be placed at the disposal of the cook, for various articles of food vary in the quantity of heat required and the period of time within which the heat should be delivered and cooking be completed.

In the same way single-top burners should have a capacity of 10 cu. ft. per hour, while double burners should have some 15 to 18 cu. ft. per hour, the consumption being a matter of optional and local regulation. The grate should be situated at least 1.5 in. above the burner, or high enough to prevent the impinging of the flame-cone upon the bottom of the cooking-vessel, because such vessels have a tendency to lower the flame temperature, thereby preventing complete combustion. The burners may be kept adjusted by keeping tight the set-screw on the shutter of the air-mixer after proper regulation has once been made. It is necessary to keep the drilled holes thoroughly cleansed and free from carbon deposits; this may be accomplished in most instances by a fortnightly washing in sal-ammoniac.

Baking.—The burning of bread as well as other food may be due to placing it in the oven too soon after lighting; the oven is not then hot enough to radiate much heat and the heat comes from the direction of the flames only. Burning of bread may be due also to the use of pans of great depth for baking, their deep sides depriving the upper portion of their contents from its necessary quota of heat. It may, of course, be caused by defective construction of the oven, which in this day of gas-range competition is extremely unusual. Defective regulation, insufficient insulation of the oven-bottom, etc., may also be contributory causes. Care should be taken that all the drilled holes in the burners are clear and free from stoppage and that the flame produced is of a proper

color and forms with the air-mixture a jet in the shape of a perfectly symmetrical cone. There is no economy in placing food in the oven before it attains the proper heat, which under usual conditions is approximately four minutes. This period of preparation permits the walls and linings of the range to heat up and the atmosphere of the range to obtain the temperature requisite to efficient service. This is especially necessary with a gas-range, because the intense heat is localized immediately beneath the oven, usually within 3 in. under the bottom of the bread, whereas, with the ordinary coal-range, the oven is more or less insulated from direct heat, but is heated by the products of combustion, all parts equally and practically simultaneously.

In extreme cases a covered baking-pan with a ventilator may be used; this ventilator should remain closed until the bread is nearly baked. This cover should be removed at from two to three minutes before taking the bread from the oven, which period is usually sufficient to properly brown it. During this final period the heat should be increased to the maximum capacity of the burner.

The rule, to preheat the oven, should be invariable, and it is usually best to accomplish this by using the maximum capacity of the oven-burner, after which the flames may be somewhat reduced until a slow, even heat is secured. As before mentioned, the temperature is again increased to maximum during the "browning" period. The temperature necessary in ovens, of course, varies directly with the food to be cooked, pastries, etc., requiring intense quick heat, while other food requires slow, even temperature.

Gas-ranges when leaving the factory are generally regulated for the average pressure in the town in which they are to be installed. In every town, however, the district or local pressure varies widely. It is occasionally necessary to change this rating on the part of the range, which is done either by supplying a different nozzle or tip, these being furnished by the range-makers and located in the gas-inlet of the burner. Gas-ranges cannot be expected to operate efficiently under a greater variation than that of 1.8 to 3.5 in., 2 to 2.5 in. obtaining the highest efficiency. Should the district pressure vary between greater limits than these, a proper governor should be placed either upon the house service or directly before entering the gas-range itself.

Essentials.—A few of the essentials to be observed in the selection of a gas-range by any gas company are:

1. Removable burners to facilitate cleaning.
2. Snugly fitting air-shutters, convenient to adjust and fitted with set-screws to retain the adjustment.

3. Removable linings for facilitating repairing.
4. Sufficient weight of castings to prevent breakage in moving and mechanical strength, such as unusual strength on the part of hinges, brackets, and all castings subject to strain.
5. Distribution of heat in the oven.
6. Properly set burners, their position being located so as to obtain the highest efficiency in combustion.
7. Oven-burners, evenly drilled, distributing the flame in equal cones and low enough not to impinge the flame upon the baffles or heat-distributors over the bottoms.
8. Sufficient flue-opening to prevent smothering the burners, to remove aqueous vapors from the oven, and to furnish ventilation for steam.
9. Sufficient air-ports to supply ventilation to the above flues.
10. Linings of sufficient thickness, say not less than 22 or 24 B. & S. gage, so as to prevent rusting out in a reasonable length of time.
11. Proper construction of top burner to prevent leakage in cemented joints.

The quantity of heat lost by radiation in gas-ranges will average 20 to 25 per cent.

Combustion.—The drilled burner has now been almost universally adopted. The size of drill-holes for an average illuminating-gas of 2-in. pressure will average for the top burners (single burners) $\frac{3}{32}$ in. diameter. For the top burners (double) $\frac{7}{48}$ in., except in the case of double top burners with two valves, which have drilled holes of $\frac{3}{32}$ in.; even burners having two valves will average $\frac{7}{64}$ in. diameter holes.

The following excellent description of the inductor or aspirator in a gas-burner is given by P. A. Degener. The action of the inductor of an atmospheric gas-burner depends upon the friction of the moving stream of gas which draws in air around it, the kinetic energy of the gas giving power to bring the mixture to the outlet of the burner. The two essential points are: to combine the velocity and force of the gas-jet with the largest possible surface, and shape the inductive body in such a way that the incoming air will be forced against the jet.

Gas-range Cocks.—Where the range cock is used it should invariably be of the lock-wing removable-handle, socket-head type in order to insure the proper control of this valve and to prevent its use by children or ignorant persons.

It is a matter of history that ninety per cent. of the gas-range accidents which have occurred have been through a meddling with

or improper use of this cock, with the result that its service has been abandoned by at least half of the gas companies of this country. After gas-ranges are set they should be inspected thoroughly by a competent inspector, who will note pressure, adjustment, and mechanical correctness of fittings, and who should then instruct the consumer in the use of the appliance.

As it may occasionally be necessary to set the gas-ranges or gas-burning appliance in districts where the pressure is abnormally low or subject to very considerable fluctuation, having a low minimum sawed burner will be found to be advantageous, as it is less liable to flash back under sudden drops of either pressure or candle-power.

The quality of gas most efficient for the use of gas-ranges and other gas-burner appliances depends entirely upon its calorific value, which varies in the case of coal-gas, straight water-gas, or mixed gas. The gas should have, however, a value of about 650 B.t.u., and should not be less than a minimum of 16 to 17 candles; for coal-gas 18 candles are better, 20 candles for water-gas, and 18 candles for mixed gas (see table of candle-power compared with calorific value). The most satisfactory results from water-gas, however, are obtained from a 22-c.p. gas; with this gas, while it is possible to adjust a Bunsen mixture at 1.5 in. pressure, the most satisfactory results obtain under 2.5 in. pressure, the maximum permissible being about 3.5 in.

Where ranges or other heating appliances are used adjacent to walls, such walls should be invariably protected by sheet asbestos-board.

Testing Ranges.—As has been said, under very widely varying pressure conditions, or rather under conditions of extreme high or low pressure, where local governors may be deemed inadvisable, it may sometimes be best to vary the size of the nozzle used on the gas-inlet to the Bunsen burners.

These nozzles are bored or drilled according to the B. & S. or Morse standard drill gages, and to test or identify their sizes, which run usually between 30 and 45, an internal-diameter gage is used, as shown in Fig. 63, opposite. It should always be among the tools of every fuel-appliance or repair department.

An examination into the standards for gas-ranges maintained by the largest fuel-supplying companies of this country shows about the following average:

The floor test, which is made by placing a black-bulb chemical thermometer upon the floor immediately beneath the oven and just below the center of the range, should show a mean temperature of about 120 deg. Fah. in 40 minutes after lighting.

It is necessary that a black-bulb thermometer be used in order to prevent the reflection of radiant heat.

It is presumed that a gas-range oven of ordinarily good construction will attain a baking heat, viz., about 400 deg. Fah., with 650 B.t.u. gas in from 9 to 11 minutes (pressure from 1.5 to 2.0 in.).

The consumption of gas during this period of time (*i.e.*, 10 minutes) varies from 4.5 cu. ft. with air-jacketed, sheet-iron ranges to 11 cu. ft. with "all cast-iron type."

Very few makes of ranges, from a standpoint of efficiency, show identical results, those of low efficiency being sometimes compensated to some extent by points of durability, strength, etc.

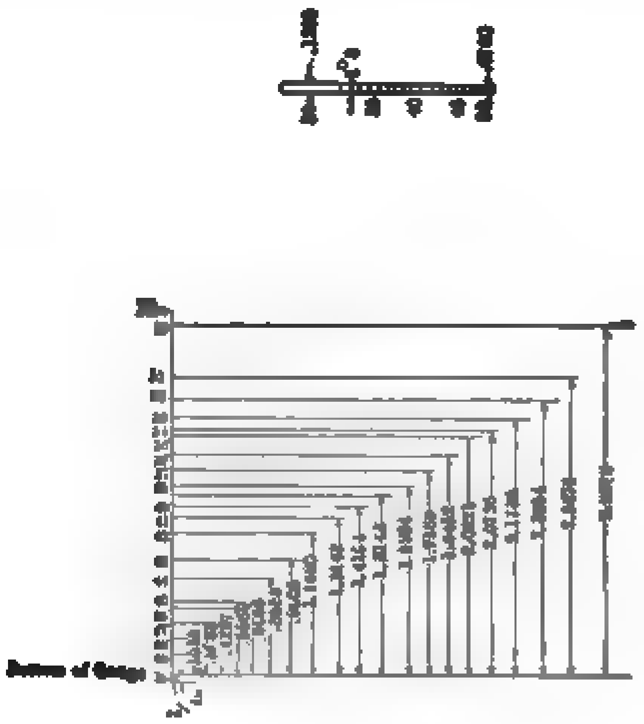


Fig. 63.—Gage for Burner-holes.

The oven test is made by perforating the side of the oven and inserting a 700-deg. Fah. straight-tube thermometer through an asbestos saddle. The saddle should shield the thermometer from contact with the case of the range, and the saddle and thermometer when inserted should completely close the orifice.

Range-ovens should be so constructed and ventilated that they will become evenly heated in all parts after the burners have been lighted for ten minutes. Both top and bottom of any food baked should be evenly browned and upper and lower racks should show uniform results and identical heat.

Moreover, the center of the oven should show no different results from its extreme edges, a test for even heat throughout the oven being best effected by placing small pieces of unglazed paper of equal size in various portions of the oven and noting the degree of equality with which they are browned.

The floor temperature test should never indicate a higher heat than 1100 deg. Fah., as any increase over this may become dangerous to woodwork.

A number of companies specify an air-space of not less than 1 inch in the bottom construction of the oven, and that there be not less than 3 inches of clear air-space between the bottom of the range and the floor. This arrangement gives practically no floor temperature at all and should produce an oven of high efficiency.

Where asbestos sheets are used, the construction should be such (see Fig. 64) as to permit their being readily interchanged.

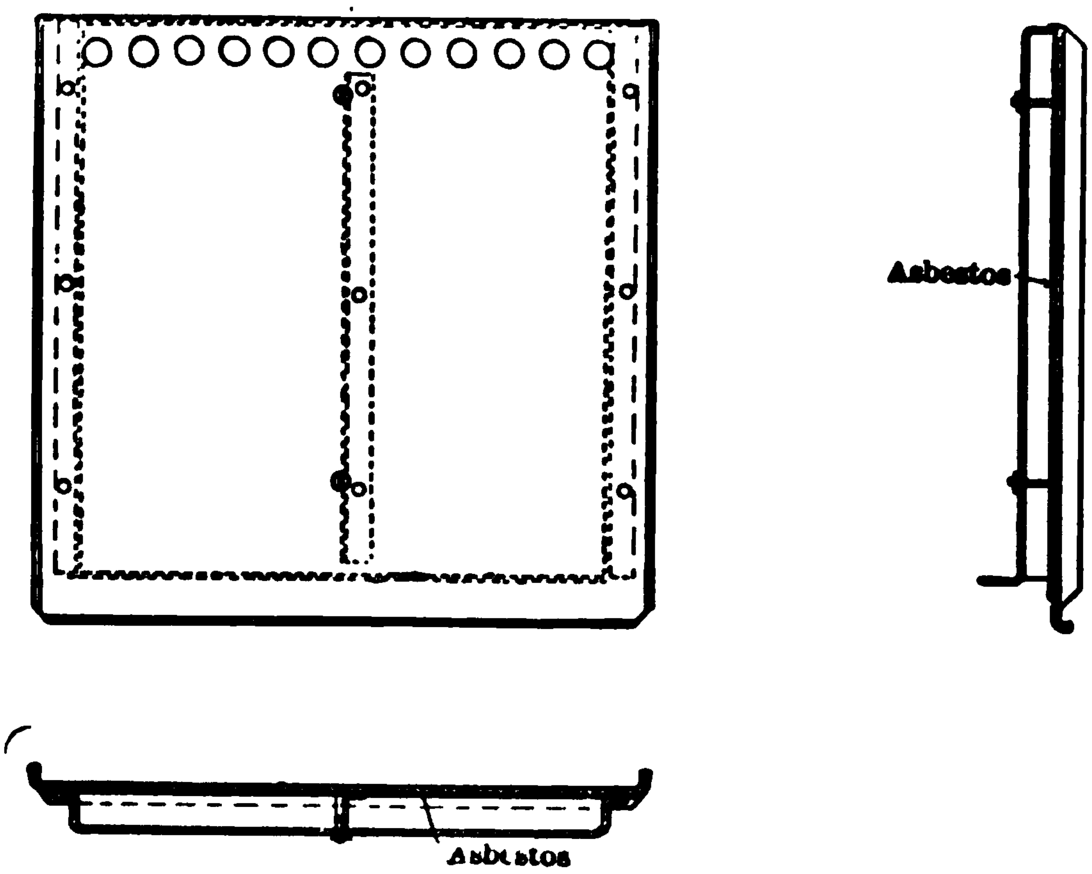


FIG. 64.—Asbestos Gas-range Lining.

A simple test for determining whether a range oven is ready for baking consists in placing an ordinary piece of white writing-paper upon the lower shelf; in the case of bread it should turn dark brown quickly; for cake it should turn golden brown when placed upon the middle shelf.

Demonstrators should be urged to, as far as possible, instruct consumers in the method of boiling, broiling, etc., within the oven instead of upon the upper burners. It is possible, in fact, to execute any manner of cooking within the oven which can be done upon the top burners, and usually much more efficiently and with better culinary result. Demonstrators and canvassers should also urge upon the consumer the absolute necessity of cleanliness in the maintenance of a range, both for the preservation of the appliance and the obtaining of efficient results.

The range should be washed at least twice a month with a stiff brush and afterwards by a cloth with warm water and a little caustic

soda. The casting should be gone over while the parts are still warm. All loose parts, including racks, burners, and any small or movable portion of the range, should be placed within the soda water and permitted to soak, after which the whole should be wiped off with a soft clean cloth and the burners lighted for a few moments after reassembling to dissipate any possible dampness and prevent rust.

The whole should then be gone over and carefully oiled with a rag containing machine-oil. This will prevent rust and is infinitely preferable to any form of stove-polish.

A set of specifications gotten out by one of the leading gas engineers is herewith appended.

Range Specifications. — The weight of a 16-in. range complete shall not be less than 150 lbs.; that of an 18-in. range not less than 175 lbs.

Top Burners.—To consist of three single, one giant, and one simmer burner. Giant burner to be the left-hand front burner. Simmer burner to be located back of the front burners and not inside of any of the burners.

To be separable with a good depth of bowl, with a well-fitting joint,—construction as shown on accompanying drawing preferred. All burners to be so placed that they can be lifted out; no bolts to be used.

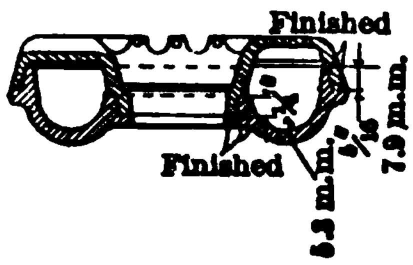


FIG. 64.—Gas-range Top Burner.

Carrying-tube.—Top burners to be open on the mixer end to admit brush for cleaning. Mixer to have adjustable shields that can be made rigid when required.

Top and Oven Mantles.—To be extra heavy $\frac{3}{4}$-in. pipe throughout.

Gage of Metal.—In the body and linings of the stove to be No. 24.

Body of Stove.—To have dead air-space not less than $\frac{1}{2}$ in. asbestos-lined.

Pipe-collar.—To take 4-in. pipe, and to be located on rear of range top.

Oven Flame-plate.—The oven flame-plate and bottom should be of not less than 20-gage metal with center braces. (See Fig. 61.) This flame-plate construction is preferred.

Oven-burners.—To be two long drilled burners, open at mixer, and to admit brush for cleaning.

Pilot-light.—To be so constructed that it will light both oven-burners, and the flame to be visible from the outside of the oven.

Valves.—Ranges to have needle-valves having independent adjustable apertures with needle-point heads that can be easily

moved with fingers for the purpose of properly adjusting the gas supply. Needle-point heads to be covered by suitable caps.

Gas Supply to Top Burners.—To be taken off manifold at back before supply is taken for oven-burners.

Gas supply to all burners should rise.

Not less than 3 in. of clear air-space to be provided between bottom of range and floor.

Doors.—To be drop pattern balanced by counterweight; no catch or spring to be used.

Gas Apertures.—To be drilled to allow a consumption by oven-burner of 27 cu. ft. each. Single-top burners to be 12 cu. ft. capacity, giant burners 18 cu. ft., water-heater burners 40 cu. ft., measured at a gas pressure of 1.2 in.

B. LIGHTING APPLIANCES.

Mantle Burners.—Incandescent gaslights increase in candle-power in direct ratio with the pressure of the gas flow, and it is the experience of the writer that they cannot be successfully operated under less pressure than 1.8 in. of water.

There are many makes of these lights, the best of which should comply with the following specifications:

First.—That both the air-inlet and gas-inlet be capable of easy and complete regulation.

Second.—That the parts be as nearly as possible interchangeable.

Third.—That the mantles burn with an even light throughout their entire service, and be of satisfactory longevity, in which latter respect the aluminum-type mantle seems to take preference over those supported by asbestos.

The gas-apertures in the regulating-valves of these burners are exceedingly small and easily clogged. It should therefore be a cardinal rule with all gas companies that their workmen should carefully examine the condition of the fixtures before installing a burner or replacing a mantle, and that this examination should reveal a clear, unimpeded flow of gas with full pressure and freedom from obstructions, this latter being caused, as a rule, by condensation in the pipes, meter, or services, and which can generally be removed by the sudden admission of compressed air from a pump to the proper condensing-chamber.

Candle-power and Heat Value.—In a lecture delivered befor the Institution of Gas Engineers, Prof. V. B. Lewes gave the following table as the average relation between candle-power and calorific value as determined by a number of tests, but said that the results in any particular case might vary 5 per cent. either way from these, and even with this qualification exception was

taken to the figures by some gas engineers. They stand, however, as the most definite statement yet published.

Candle-power.	Calorific Value, B.t.u. per Cubic Foot.			
	Coal-gas.		Carburetted Water-gas.	
	Gross.	Net.	Gross.	Net.
12	540	480	490	452
13	560	500	510	472
14	585	522	529	489
15	610	542	547	508
16	625	562	567	527
17	647	582	587	547
18	670	603	607	567
19	690	622	627	587
20	712	642	647	607

As a result of work done in the University of Michigan, Messrs. White, Russell, and Traver decided that, all other conditions being the same, the light given per cubic foot of gas, when consumed in incandescent burners, was proportionate to the calorific value of the gas, and increased directly at the rate of one candle per each additional four calories (or 15.87 B.t.u.).

With these experiments the ordinary C. Welsbach burner, with Welsbach mantles, was used, the air and gas adjustment of the burner being such as to obtain the maximum of light. Prof. V. B. Lewes claims, however, that the efficiency of the gas in an incandescent burner depends more upon the flame temperature than upon the calorific value, and cites results of certain experiments, showing a duty of from 19 to 20 candles per cubic foot from blue water-gas when burned in a certain design of Argand burner without any preadmixture of air.

The mantle itself never attains the theoretical, or even the actual, temperature of the flame, so for all practical purposes the efficiency of illuminating-gas for use in incandescent burners may be stated as being directly proportional to the calorific value. By the calorific or heat value of a fuel is meant the total number of heat-units which may be developed from it by complete combustion, the comparison being per cubic foot. The calorific value of an elementary substance can only be obtained by experiment, but that of compounds is simply calculated by an addition of the sum of the known heat value of their constituents.

Caloric Requirements for Incandescent Lighting.—Mantles can be made to give their full lighting power with low

heat-unit gas, such as blue water-gas, which runs as low as 290 B.t.u. per cubic foot. With 350 B.t.u. blue gas a first-class 80-candle-power Welsbach burner will give its full lighting power on 6½ feet of gas.

There is always a peculiarity to be noted in the case of blue gases, such as was found with the 80-c.p. burner just cited. The ordinary American Welsbach No. 71 burner consumes about 4 cubic feet of 600 B.t.u. gas to give its full lighting power. This same burner, which should theoretically burn 7 to 8 cubic feet of 300 B.t.u. gas to give the same effect, burns only about 6¼ to 6½ feet to do so. In other words, the efficiency of the blue gas relative to its heating power is greater than that of ordinary illuminating-gas.

Flat-flame Burners.—The principles governing the efficient combustion of gas for the direct production of light are very fully set forth in King's "Treatise on Coal-gas," from which the following summary has been taken: "Since the light given by a gas-flame is due principally to the raising to incandescence of particles of carbon set free by reactions occurring in the flame, to obtain the maximum amount of light it is necessary that the gas should be so consumed as to secure the setting free in the flame of the greatest possible number of carbon particles and the raising of the particles to the highest possible temperature. These two conditions can only be secured by the proper regulation of the amount of air supplied to the gas-producing flame, and of the manner in which the air is brought into contact with the gas. The formation of the carbon particles being due to decomposition of the hydrocarbon constituents of the gas, principally by effect of heat, anything which tends to cause the combustion of these hydrocarbons before they are sufficiently heated to be decomposed reduces the amount of light given by the flame by reducing the number of carbon particles present in it. And since the amount of light produced by any given number of carbon particles increases with the temperature to which they are raised, anything that tends to lower the temperature of the flame also reduced the amount of light given by it.

"Any admixture or intermingling of air and gas reduces the illuminating power, both by partially consuming the hydrocarbons before they are sufficiently heated to be decomposed, and so reducing the number of carbon particles in the flame, and also by cooling the flame. Any over-draught by which an excess of air is brought into contact with the flame so as to be heated by it reduces the illuminating power by cooling the flame. To secure the maximum amount of light from the gas, it is therefore necessary that the air should be brought into contact with the gas in just the proper amount required for its complete combustion, and in such a way that the contact takes place only on the surface of the flame. With

flat flames the great cause of intermingling of air and gas and of excess rush of air against the surface of the flame is a high velocity of exit of the gas from the burner-tip into the atmosphere. The velocity of exit increases rapidly with the pressure at which the gas is supplied to the burner-tip. It is therefore essential that the pressure at the tip be low. With an Argand burner this pressure can be reduced to practically nothing, but with flat-flame burners a certain amount of pressure is necessary to develop the flame to its proper shape, this being especially the case with union jet (fish-tail) burners.

"Any swirling motion in the gas also tends to produce an intermingling of gas and air as well as a disagreeable noise, and therefore the arrangement of the burner should be such as to supply the gas to the points of ignition in an even flow free from eddies or rotary motion. To insure that all the gas shall be consumed to the best advantage, it is necessary that the proper proportions between the gas and air supply shall exist over the whole surface of the flame, and therefore that the gas shall be supplied in equal quantity at all the points of ignition.

"The following details of construction have been adopted to put into effect the principles brought out above. To insure the existence of a low pressure at the burner-tip the improved forms of flat-flame burners are provided either with some forms of governor, which maintains the pressure at the tip constantly at the proper point, no matter how much the pressure on the piping increases, or else with a 'check,' which is usually a metal, steatite, or lava disk inserted in the burner pillar so as to cut off any flow of gas to the tip except through a hole in the disk, the area of which is smaller than that of the opening in the tip, the relation between the area of the opening in the check and that of the opening in the tip varying with the pressure at which the burner is designed to be used, that is, the higher the pressure the smaller the hole in the check for same-sized tip.

"To produce a steady, even flow of gas without any swirling motion, some burners have placed between the check and the tip a screen of fine wire gauze, which breaks up any currents and renders the flow of gas uniform throughout the whole area of the burner pillar, while others depend upon the steadying action produced by the large area of the burner pillar above the check as compared with the area of the opening in the tip.

"To secure an equal supply of gas to all parts of the flame, slit (batswing) burners are made with what is called a hollow top, by means of which the slit is kept at the same depth in all parts instead of being much thicker at the top than at the sides, as it would necessarily be if the top of the tip were left solid instead of hollowed

out inside to conform with its shape outside. The effect of extra thickness at any place is that less gas passes through the slit at the thick place, and that consequently the conditions are not the same at all parts of the flame. A further improvement in this direction, introduced in some burners, consists in cutting the slit with a circular saw applied from above the tip, and thus making it curved on the bottom instead of flat, as is the case when it is cut by sawing in the ordinary way. With the flat-bottom slit some of the gas issues at right angles to the axis of the burner, only to be folded back on the upper part of the flame by the upward draught of air caused by the heat of the flame, while with a curved-bottom slit this effect is avoided, as the gas issues in a direction along which it is free to travel without being turned aside, and the flame is thus kept of more even thickness throughout.

"In Snugg's table-top burners the effect of the upward rush of air in increasing the thickness of the lower edges of the flame is still further guarded against by forming a circular 'table' immediately under the top of the tip, the projection of which deflects the currents of air and prevents them from rising vertically against the flame."

C. INDUSTRIAL APPLIANCES.

Operation.—For gas-furnaces and industrial appliances the air pressure should have a minimum of one pound and a maximum of two. The exact air pressure, of course, depends upon the thermal quality of the gas, it being necessary to obtain the exact ratio between the two for complete combustion.

Flashing back in all forms of Bunsen burners is caused by the flame traveling back through the burner to the issuing gas-jet and may be due to insufficient velocity of exit at the burner-head of the gas-air mixture, to a too highly heated burner-head, to the exit orifices of the burner-head being too small, to the mixing-tube being too hot, etc.; it may be overcome by increase of gas pressure or the removal of the mixer to a further distance from the heat area. It is sometimes caused by the faulty design of the burner, but in practice more often by the clogging of the burner or air-hole strainer, thereby reducing the gas velocity, as before mentioned. It is occasionally remedied by the intervention of one or more wire screens between the head of the burner and the air-intake. This acts on the principle of the Davy lamp, reducing the temperature of the gas to below the combustion-point. An angle bend or deflection in the pipe intervening between the air-mixture and burner outlet tends to prevent flashing back, which fact is utilized in the construction of the Martin incandescent burner.

A test made by the Troy Laundry Machine Co. shows a saving

of one-half of the gas consumed by admission of air to Bunsen burners under pressure, as against the use of atmospheric burners.

The minimum pressure of gas for gas-arcs should never be less than 2 in., 3 in. being good average. The maximum of low-pressure efficiency is usually obtained at about 4.5 in., but under high-pressure conditions the result obtained at one pound per sq. in. pressure practically doubles the efficiency of the appliance.

Where air is admitted to Bunsen burners under considerable pressure and the gas and air are brought together at the burner, there is a chance, due usually to some stoppage in the burner, of the air backing up into the meter and forming there an explosive mixture. To prevent this, it is a safeguard to place a free-swinging check-valve on installations of this kind between the burner and the meter.

The writer's tests of efficiency of burners under stereotyping crucibles and linotype machines vary between 60 and 70 per cent. The complete combustion, of course, depends upon the chemical constituents of the gas; it will run, however, between two and three times the gas volume in general practice.

The Bunsen mixture or complete combustion of gas through the preadmixing of air is best observed by its gradation in color. The pure gas burns a yellow flame; the preadmixture of air is indicated by a blue cone, an increase of air showing green, which in excess shades down almost to the white of an alcohol flame, high economy in the admixture, continuing the air addition, stopping just short of the flashing-back point.

The writer's data show the highest record of flame temperature obtained from a Bunsen flame to be 1950° to 2000° C.

Consumption.—The consumption of burners used in various industrial furnaces and processes has been found to be as follows:

Appliances.	Average Consumption, Cu. Ft. per Yr.	Appliances.	Average Consumption, Cu. Ft. per Yr.
Rivet-heaters	300,000	Braziers	75,000
Meat-branding machine.	150,000	Caldron heaters	120,000
Hotel range	300,000	Soldering furnaces	40,000
Tinning-bath	300,000	Gas-arc lamps	24,000
Linotype machine	50,000	Tailor-iron heaters	40,000
Gas forges	300,000	Laundry irons	18,000
Gas bakery ovens	200,000	Gas manglers	50,000
Gas steam-tables	200,000	Glue pots	40,000
Enameling ovens	120,000	Water-stills	30,000
Confectioners' gas-stoves	120,000	Gas broilers	50,000
		Incubators	10,000
Popcorn poppers and peanut roasters	50,000	Gas-engines per actual working h.p.	60,000

Gas-engines.—In order to find the size of meter required for a gas-engine, multiply the brake horse-power by 3.4+5 for the number of lights of meter.

Exhaust-pipe.—From 1 to 5 horse-power requires a 1-in. to $1\frac{3}{4}$-in. pipe; above that size the diameter of the pipe should equal $D=0.528$ h.p.$^{0.57}$, or about $0.528\times$ the square root of the horse-power. The heat of the exhaust-pipe is great and likely to burn wood if too near. Bends of 6 in. diam. or more should be used and no elbows or T's allowed. Turn the outlet of the pipe to look downward. To prevent excessive noise, the pipe can be carried into a drain-pit and surrounded with stones covered over with straw.

Cooling-water.—About 5 gallons of water per horse-power per hour will be required for the cylinder if the water be taken direct from the main. If hard water is used, a handful of washing-soda should be used in the tank every month.

Circulating-tank.—About 20 or 30 gallons per h.p. of cooling-water with pipes from 1 to 3 in. diam. are necessary. The return-pipe is usually a little larger than the flow, with a rise of at least 2 in. per foot leading to the tank at the normal water-level.

PART III.

GENERAL TECHNICAL DATA.

CHAPTER XIX.

PROPERTIES OF GASES.

A. Composition.
B. Volume.
C. Specific Gravity.
D. Specific Heat.
E. Calorific Value.
F. Temperatures.
G. Heat Data.

A. COMPOSITION OF GASES.

Various Gases.—The following table is given by **Bates as the** average percentage constitution of the gases named.

AVERAGE COMPOSITION OF GAS (PER CENT).

Gases.	CO_2	O	CO	N	C_2H_4	CH_4	H
Flue gas (bituminous coal)	9.65	8.55	0.00	81.80	0.00	0.00	0.00
Hoffman coke-oven gas	1.41	0.43	6.49	0.00	2.04	36.31	33.32
Producer-gas (bituminous coal)	2.05	0.30	27.00	55.30	0.40	2.50	12.00
Producer-gas (anthracite coal)	2.50	0.30	27.00	57.00	0.00	1.20	12.00
Water-gas	4.00	0.50	45.00	2.00	0.00	3.50	45.00
Natural gas	0.60	0.80	0.60	3.00	1.00	72.00	22.00
Coal-gas	0.30	0.40	0.60	2.80	4.30	36.50	48.10

The following table is credited to J. M. Morehead.

APPROXIMATE COMPOSITION OF ORDINARY GASES.

Gas.	Carbon Dioxide.	Illuminants.	Oxygen.	Carbon Monoxide.	Hydrogen.	Methane.	Nitrogen.	B.t.u. per Cubic Foot.	Specific Gravity.
Water-gas 24 c.p.	4.5	13.0	0.5	29.0	32.0	16.0	5.0	720	0.63
Coal-gas 16 c.p.	2.0	5.5	0.5	11.5	43.5	35.0	2.0	610	0.45
Acetylene (commercial)	.....	96.0	1.0	.....	.....	.....	4.0	1600	0.92
Flue gas	16.0	.....	4.5	0.5	.....	.....	79.0	.....	1.06
Pintsch gas	0.5	23.5	0.5	1.0	18.5	52.5	3.5	1100	0.73
Engine exhaust	8.0	.....	17.0	.....	.....	.....	75.0	.....	1.04
Producer-gas	6.0	.....	.....	22.0	11.0	3.0	58.0	150	0.89
Natural gas	2.0	2.7	0.1	1.0	.....	88.1	5.2	900	0.56
Blue water-gas	3.0	.....	.....	43.25	50.0	0.5	3.25	350	0.42
Air	.....	.....	20.7	.....	.....	.....	79.3	.....	1.00

The above figures are given as an average of those which ordinarily obtain in the best practice. Local conditions and requirements probably will, of course, vary these figures in individual instances.

Properties.—Another authority compiles the following characteristics of gases usually met with in metallurgical calculations.

CARBONIC ACID OR CARBON DIOXIDE.

Formula	CO_2
Composition by weight	73.7% O, 27.3% C
Density or specific gravity, air = 1	1.529
Lbs. per cubic foot	.116
Cubic feet per lb.	8.62
Cubic feet air necessary to consume 1 cu. ft.	Non-cumbustible
B.t.u. per cubic foot	Non-combustible
Solubility: Vols. absorbed in 1 vol. water	1.23

ILLUMINANTS OR HEAVY HYDROCARBONS.

Formula	90% C H,
Composition by weight	85.7% C, 14.3% H
Density or specific gravity, air = 1	.985
Lbs. per cubic foot	.074
Cubic feet per lb.	13.38
Cubic feet air necessary to consume 1 cu. ft.	14.34
B.t.u. per cubic foot	1675
Solubility: Vols. absorbed in 1 vol. water	.15

OXYGEN.

Formula	0
Composition by weight	100% O
Density or specific gravity, air = 1	1.105
Lbs. per cubic foot	.084
Cubic feet per lb	11.94
Cubic feet air necessary to consume 1 cu. ft	Non-combustible
B.t.u. per cubic foot	Non-combustible
Solubility: Vols. absorbed in 1 vol. water	.028

CARBONIC OXIDE OR CARBON MONOXIDE.

Formula	CO
Composition by weight	42.9% C, 57.1% O
Density or specific gravity, air = 1	.967
Lbs. per cubic foot	.073
Cubic feet per lb	13.57
Cubic feet air necessary to consume 1 cu. ft	2.39
B.t.u. per cubic foot	341
Solubility: Vols. absorbed in 1 vol. water	.023

HYDROGEN.

Formula	H
Composition by weight	100% H
Density or specific gravity, air = 1	.069
Lbs. per cubic foot	.006
Cubic feet lbs	189.23
Cubic feet air necessary to consume 1 cu. ft	2.39
B.t.u. per cubic foot	345
Solubility: Vols. absorbed in 1 vol. water	.019

METHANE OR MARSH GAS.

Formula	CH_4
Composition by weight	75% C, 25% H
Density or specific gravity, air = 1	.556
Lbs. per cubic foot	.0422
Cubic feet per lb	23.72
Cubic feet air necessary to consume 1 cu. ft	9.56
B.t.u. per cubic foot	1065
Solubility: Vols. absorbed in 1 vol. water	.035

NITROGEN.

Formula	N
Composition by weight	100% N
Density or specific gravity, air = 1	.971
Lbs. per cubic foot	.073
Cubic feet per lb	13.57
Cubic feet of air necessary to consume 1 cu. ft	Non-combustible
B.t.u. per cubic foot	Non-combustible
Solubility: Vols. absorbed in 1 vol. water	.015

ACETYLENE.

Formula	C_2H_2
Composition by weight	93.3% C, 7.7% H
Density or specific gravity, air = 1	.918
Lbs. per cubic foot	.069
Cubic feet per lb	14.32
Cubic feet air necessary to consume 1 cu. ft.	11.91
B.t.u. per cubic foot	1600
Solubility: Vols. absorbed in 1 vol. water	1.11

AIR.

Formula	Mixture O and N
Composition by weight	77% N, 23% O
Density or specific gravity, air = 1	1.000
Lbs. per cubic foot	.076
Cubic feet per lb	13.15
Cubic feet air necessary to consume 1 cu. ft.	Non-combustible
B.t.u. per cubic foot	Non-combustible
Solubility: Vols. absorbed in 1 vol. water	.017

SPECIFIC GRAVITY, WEIGHT, AND SOLUBILITY IN WATER OF VARIOUS GASES AT 60° FAHR. AND 30 IN. BAROMETER.

Name.	Specific Gravity, Air Equal 1.000.	Weight of a Cu. Ft. in Pounds Avoir.	Weight of a Cu. Ft. in Grains.	Number of Cu. Ft. Equal to 1 lb.	Solubility. 100 Vols. of Water Absorbed.
Hydrogen	0.0691	0.00529997	37.09	188.68	1.93 vols
Light carburetted hydrogen	0.559	0.0428753	300.12	23.32	3.91 "
Ammonia	0.590	0.045253	316.77	22.09	72,720 "
Carbonic oxide	0.967	0.0741689	519.18	13.48	2.43 "
Olefiant gas	0.968	0.0742456	519.71	13.46	16.15 "
Nitrogen	0.9713	0.07449871	521.49	13.42	1.48 "
Air	1.000	0.0767	536.90	13.03	1.70 "
Nitric oxide	1.039	0.0796913	557.83	12.54	Not soluble
Oxygen	1.1056	0.08479952	593.59	11.79	2.99 vols
Sulphureted hydrogen	1.1747	0.09009946	630.69	11.09	323.26 "
Nitrous oxide	1.527	0.1171209	819.84	8.53	77.78 "
Carbonic acid	1.529	0.1172743	820.92	8.52	100.20 "
Sulphurous acid	2.247	0.1723449	1206.41	5.80	4276.60 "
Chlorine	2.470	0.189449	1326.14	5.27	236.80 "
Bisulphide of carbon	2.640	0.202488	1417.41	4.93	Not soluble

B. VOLUME OF GASES.

Expansion of Gases.—According to Professor Lineham, "two laws govern the varying volume of a gas, according to whether temperature or pressure be kept constant. The first law of gas expansion, discovered by Boyle in 1662 and verified by Marriotte in 1676, states that the volume of a given portion of gas varies inversely as its pressure if the temperature be constant. Shown by symbols,

$$V \text{ varies as } \frac{1}{P} \quad \text{and} \quad PV = \text{a constant.}$$

The relation of P and V is shown by diagram in Fig. 66, the ordinates PP' of the curve representing pressure and the abscissæ VV' corresponding volumes, a temperature $t°$ being main-

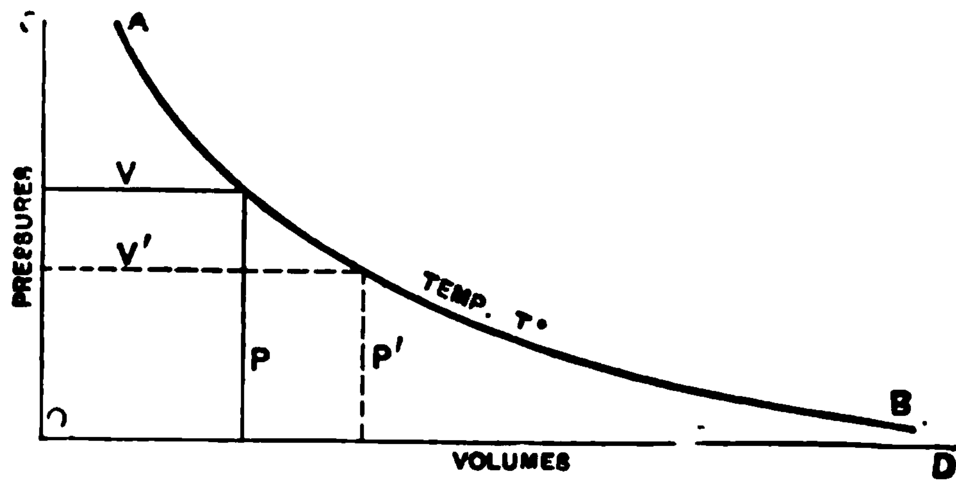


FIG. 66.—Relation of Volume to Pressure.

tained. Only one curve, the rectangular hyperbola, has ordinate × abscissa constant throughout, and that is the form of the curve AB. Although always approaching the co-ordinates OC, OD, it only meets them at infinity.

Isothermals.—By reason of equality of temperature, AB is also known as the isothermal of a perfect gas, that is, of a gas following Boyle's law perfectly. Marriotte's tubes, Fig. 67, prove fairly well the accuracy of this law. A and B are strong glass tubes, A being sealed at top, level with mark 10, and C is a stout though flexible rubber tube. Taking the first position, mercury is poured into the funnel D until about level with 0, and a final adjustment made by moving B up and down. A portion of air, imprisoned in the leg A, supports a pressure of one atmosphere, D being open, and has the volume of 10 in.

Raise B until the mercury reaches 35″, and the fluid in A will have risen to 5″. The difference of mercury levels is now 30 in., representing an additional pressure of one atmosphere; so the air

now supports two atmospheres and has a volume of 5 in., or $P \times V$ is constant. Intermediate experiments can easily be obtained and the law more generally proved. The so-called permanent gases are practically perfect, and others fairly so, if measured at a much higher temperature than that of liquefaction.

The second law of gas expansion was discovered by Charles in

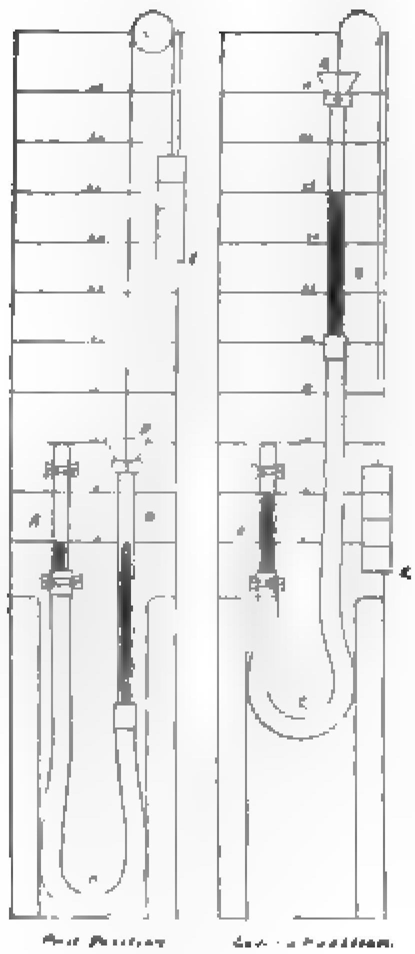


Fig. 67.—Apparatus Illustrating Boyle's Law.

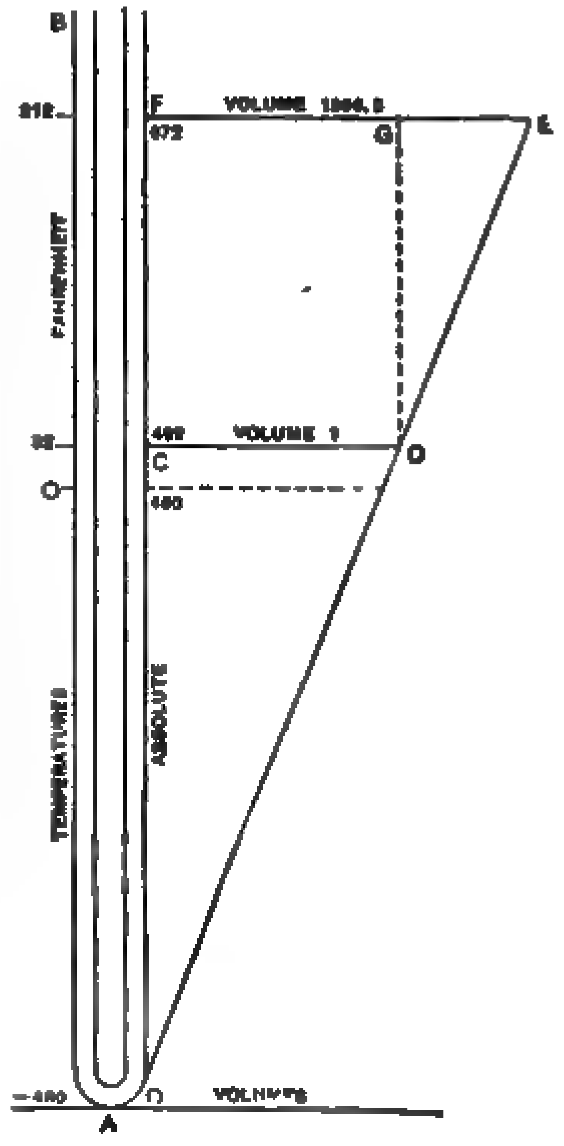


Fig. 68.—Relation of Volume to Temperature.

1787, published by Dalton in 1801, and by Gay-Lussac in 1802, all independently. The last-named completely verified the law, which states that the increase in volume of a given portion of gas varies directly as the increasing temperature, if the pressure be constant; or, if V be original volume, V_1 the increase, V_2 the total volume after increase, and $t°$ the rise in temperature,

$$V_1 \text{ varies as } t° \quad \text{and} \quad V_1 = Vat°,$$

a being the coefficient of cubical expansion. V and a are constant and $t°$ the only variable; hence

$$V_2 = V + V_1 = V + (Vat°) = V(1 + at°).$$

The coefficients of linear expansion for solids vary with the substance, as do also their cubical coefficients (being three times the linear ones); but all gases not only expand regularly, but each to the same amount, increase of temperature being equal, one coefficient serving for all. Between 32° and 212° the total expansion is $0.3665V$ or $\frac{0.3665}{180} = 0.00204$ for each degree: figures found by Gay-Lussac, expanding the air in an air-thermometer, the bulb dipping in heated water, whose temperature was taken by mercury-thermometer.

Absolute Zero of Temperature.—Let AB, Fig. 68, be an air-thermometer with an air-tight piston C, and the volume AC be called 1, the temperature being 32°. Set off ordinate CD for volume at 32°, and FE for that of 212°. The latter will be 1.3665, and the gradual volumetric increase be shown by the straight line DE. Supposing the law true for extreme limits, line DA (a production of DE) will mark out the volume as we decrease the temperature, ultimately meeting AB in A. Then at A the volume will have decreased to nothing, and all the heat will have been taken out of the air. Though these possibilities are absurd, their supposition enables us to fix a zero-point having important advantages in thermo-volumetric calculations.

To find A, the absolute zero of temperature, we proceed by similar triangles:

$$\frac{AC}{CD} = \frac{DG}{GE} \quad \text{and} \quad AC = \frac{DG \times CD}{GE} = \frac{180 \times 1}{1.3665} = 492° \text{ about,}$$

then

$$A\text{'s reading} = 492° - 32° = 460° \text{ below zero F.}$$

Any ordinary temperature F. may, then, be made absolute by adding 460, and while $t°$ indicated Fahrenheit readings, r will show absolute readings.

Note that Fig. 68 is a graphic statement of Charles' law, AE being an isopiestic or line of constant pressure, and AB a line of constant temperature.

Combination of Boyle's and Charles' Laws.—PV is invariable for any particular position on the thermometric scale; but

if $t°$ be raised, the value of PV will be raised also. In Fig. 68, if P be kept constant, v will vary as t; so if V increases at the same rate as t, any series of multiples of V will similarly increase; and as P would be such a multiplier in Fig. 68, then

$$PV \text{ varies as } t \quad \text{and} \quad PV = ct,$$

which is strictly general, c being a coefficient depending on the gas.

Taking one pound of air at a temperature of 32°, and at atmospheric pressure, reckoning in lbs. per sq. ft. and in cubic feet, Regnault found by experiment that

$$PV = 26{,}214 = ct, \quad \text{then} \quad c = \frac{26{,}214}{32+460} = 53.28.$$

For superheated steam $c = 85.5$.

The above formula gives P or V at any temperature, when c is known.

Three States of Matter.—These, the solid, liquid, and gaseous, are well understood, and it is also now admitted that all bodies are capable of existence in each case successively, though not necessarily at the normal pressure and temperature. Taking one pound of any substance and applying the specific heat due to its state, its temperature rises one degree, and as the specific heat is approximately regular for each state, practically the whole heat is registered on the thermometer. But in all substances two critical points occur, called the points of fusion and evaporation, and known respectively in case of water as the 'freezing- and boiling-points'; at these points additional heat is absorbed merely to do the work of rearranging the molecules, of fusing or melting on the one hand and of evaporating on the other hand. Such 'latent' heat is not observable on the thermometer and must, therefore, be otherwise detected."

SOME OF THE MORE COMMON GASES.

Gas.	Symbol.	Molecular Weight.	Gas.	Symbol.	Molecular Weight.
Ammonia	NH_3	17	Nitrogen	N_2	28
Atmospheric air	......	......	Nitrous oxide	N_2O	44
Bromine	Br_2	160	Nitric oxide	NO	30
Chlorine	Cl_2	71	Nitrous anhydride	N_2O_3	76
Carbonic oxide	CO	28	Nitric peroxide	NO_2	46
Carbonic anhydride	CO_2	44	" "	N_2O_4	92
Ethylene	C_2H_4	28	Oxygen	O_2	32
Hydrogen	H_2	2	Sulphureted hydrogen	H_2S	34
Hydrogen chloride	HCl	36.5	Sulphurous anhydride	SO_2	64
Iodine	I_2	254	Sulphur	S_2	64
Methane	CH_4	16	Water	H_2O	18
Mercury	Hg	200			

WEIGHT OF AIR CONTAINING AQUEOUS VAPOR.

(Under an atmospheric pressure of 29.921 inches of mercury.)

Temperature, Fah. Deg.	Weight of One Cubic Foot of Dry Air, Lbs.	Vapor Tension of Water-vapor, Inches of Mercury.	Tension of the Air in a Mixture of Air and Water-vapor, Inches of Mercury	Mixtures of Air Saturated with Water-vapor.			
				Weight per Cubic Foot			Weight of Water-vapor Mixed with One Pound of Air, Lbs.
				Air, Lbs.	Water-vapor, Lbs.	Total Mixture, Lbs.	
0	0 0864	0.044	29.877	0.0863	0.000070	0 086379	0.00092
12	.0842	0.074	29.849	.0840	.000130	084130	.00155
22	.0824	0.118	29.803	.0821	000202	082302	00245
32	0807	0.181	29.740	.0802	000304	080504	00379
42	.0791	0.267	29.654	.0784	.000440	.078840	.00561
52	.0776	0 388	29.533	0766	000667	.077227	.00819
62	.0761	0.556	29.365	0747	.000881	075581	01179
72	0747	0.785	29.136	0727	.001221	073921	01680
82	0733	1.092	28.829	0706	.001667	.072267	02361
92	.0720	1.501	28.420	0684	002250	.070717	03289
102	0707	2.036	27.8 5	.0659	.002997	.068897	.04547
112	.0694	2.731	27 190	0631	003946	067046	.06253
122	.0682	3.621	26 300	0599	005142	065042	08584
132	.0671	4.752	25.169	.0564	.006639	.063039	11771
142	.0660	6.165	23.750	.0524	.008473	060873	16170
152	.0649	7.930	21.991	.0477	.010716	.058416	22465
162	.0638	10.099	19.822	0423	.013415	.055715	31713
172	.0628	12.758	17.163	.0360	016682	.052682	.46338
182	.0618	15.960	13.961	.0288	020536	.049336	71300
192	.0609	19.828	10.093	.0205	.025142	.045642	1 22643
202	.0600	24.450	5.471	.0109	.030545	041445	2 80230
212	.0591	29.921	0.000	.0000	036820	.036820	infinite

TEMPERATURE CORRECTION FOR BAROMETRIC READINGS TO 60 DEG. F. AND 30 INCHES.

(Divide observed volume by the factor found under column of observed temperature and opposite observed barometer.)

Therm.	32°	34°	36°	38°	40°	42°	44°	46°	48°	50°	52°	54°	56°	58°
Bar., In.														
28.0	0.998	0.993	0.988	0.984	0.979	0.974	0.970	0.965	0.960	0.956	0.951	0.946	0.942	0.937
28.1	1.002	0.997	0.993	0.988	0.983	0.978	0.973	0.969	0.964	0.959	0.955	0.951	0.945	0.941
28.2	1.006	1.001	0.996	0.991	0.986	0.981	0.977	0.972	0.967	0.963	0.958	0.953	0.949	0.944
28.3	1.009	1.004	1.000	0.995	0.990	0.985	0.980	0.976	0.971	0.966	0.961	0.957	0.952	0.947
28.4	1.012	1.007	1.002	0.998	0.993	0.988	0.984	0.979	0.974	0.970	0.965	0.960	0.955	0.951
28.5	1.016	1.011	1.006	1.001	0.997	0.992	0.987	0.983	0.978	0.973	0.968	0.964	0.959	0.954
28.6	1.020	1.015	1.010	1.005	1.001	0.995	0.991	0.986	0.981	0.977	0.972	0.967	0.962	0.958
28.7	1.023	1.018	1.013	1.009	1.004	0.999	0.994	0.990	0.985	0.980	0.975	0.970	0.966	0.961
28.8	1.027	1.022	1.017	1.012	1.007	1.003	0.998	0.993	0.988	0.984	0.979	0.974	0.969	0.964
28.9	1.031	1.026	1.021	1.016	1.011	1.006	1.001	0.997	0.992	0.987	0.982	0.977	0.973	0.968
29.0	1.034	1.029	1.024	1.019	1.014	1.010	1.005	1.000	0.995	0.990	0.986	0.981	0.976	0.971
29.1	1.038	1.033	1.028	1.023	1.018	1.013	1.008	1.004	0.999	0.994	0.989	0.984	0.979	0.975
29.2	1.041	1.036	1.031	1.026	1.021	1.017	1.012	1.007	1.002	0.997	0.992	0.988	0.982	0.978
29.3	1.045	1.040	1.035	1.030	1.025	1.020	1.015	1.011	1.006	1.001	0.996	0.991	0.986	0.981
29.4	1.048	1.043	1.038	1.033	1.028	1.024	1.019	1.014	1.009	1.004	0.999	0.995	0.990	0.985
29.5	1.052	1.046	1.041	1.036	1.032*	1.027	1.022	1.018	1.013	1.008	1.003	0.998	0.993	0.988
29.6	1.055	1.050	1.045	1.040	1.036	1.031	1.026	1.021	1.016	1.011	1.006	1.001	0.996	0.992
29.7	1.059	1.054	1.049	1.044	1.039	1.034	1.029	1.025	1.019	1.015	1.010	1.005	1.000	0.995
29.8	1.063	1.058	1.053	1.048	1.013	1.038	1.033	1.028	1.023	1.018	1.013	1.008	1.003	0.998
29.9	1.066	1.061	1.056	1.051	1.046	1.041	1.036	1.031	1.026	1.022	1.017	1.012	1.007	1.002
30.0	1.070	1.065	1.060	1.055	1.050	1.045	1.040	1.035	1.030	1.025	1.020	1.015	1.010	1.005
30.1	1.073	1.068	1.063	1.058	1.053	1.048	1.043	1.038	1.033	1.029	1.024	1.019	1.014	1.009
30.2	1.076	1.071	1.066	1.062	1.057	1.052	1.047	1.042	1.037	1.032	1.027	1.022	1.017	1.012
30.3	1.080	1.075	1.070	1.065	1.060	1.055	1.050	1.045	1.040	1.036	1.030	1.025	1.020	1.015
30.4	1.084	1.079	1.074	1.069	1.064	1.059	1.054	1.049	1.044	1.039	1.034	1.029	1.024	1.019
30.5	1.087	1.082	1.077	1.072	1.067	1.062	1.057	1.052	1.047	1.042	1.037	1.032	1.027	1.022
30.6	1.090	1.085	1.080	1.075	1.071	1.066	1.061	1.056	1.051	1.046	1.041	1.036	1.031	1.026
30.7	1.094	1.089	1.084	1.079	1.074	1.069	1.064	1.059	1.054	1.049	1.044	1.039	1.034	1.029
30.8	1.098	1.093	1.088	1.083	1.078	1.073	1.068	1.063	1.058	1.053	1.048	1.043	1.037	1.032
30.9	1.101	1.096	1.091	1.086	1.081	1.076	1.071	1.066	1.061	1.056	1.051	1.046	1.041	1.036
31.0	1.105	1.100	1.095	1.090	1.085	1.080	1.075	1.070	1.065	1.060	1.055	1.049	1.045	1.039

TEMPERATURE CORRECTION FOR BAROMETRIC READINGS TO 60 DEG. F. AND 30 INCHES—*Continued.*

Therm	60°	62°	64°	66°	68°	70°	72°	74°	76°	78°	80°	82°	84°
Bar., In.													
28.0	0.932	0.927	0.922	0.917	0.912	0.907	0.902	0.897	0.892	0.887	0.881	0.875	0.870
28.1	.936	.930	.926	.921	.916	.911	.905	.900	.895	.890	.884	.879	.873
28.2	.939	.934	.929	.924	.919	.914	.909	.904	.898	.893	.887	.882	.876
28.3	.942	.937	.932	.928	.922	.917	.912	.907	.902	.896	.891	.885	.880
28.4	.946	.941	.936	.931	.926	.921	.915	.910	.905	.900	.894	.888	.883
28.5	.949	.944	.939	.934	.929	.924	.919	.914	.908	.903	.897	.892	.886
28.6	.953	.947	.943	.938	.932	.927	.922	.917	.912	.906	.901	.895	.889
28.7	.956	.951	.946	.941	.936	.931	.925	.920	.915	.909	.904	.898	.893
28.8	.959	.954	.949	.944	.939	.934	.929	.924	.918	.913	.907	.901	.896
28.9	.963	.958	.953	.948	.942	.937	.932	.927	.921	.916	.910	.905	.899
29.0	.966	.961	.956	.951	.946	.941	.935	.930	.925	.919	.914	.908	.903
29.1	.969	.964	.959	.954	.949	.944	.939	.933	.928	.923	.917	.911	.906
29.2	.973	.968	.963	.958	.952	.947	.942	.937	.931	.926	.920	.914	.909
29.3	.976	.971	.966	.961	.956	.950	.945	.940	.935	.929	.923	.918	.912
29.4	.980	.975	.969	.964	.959	.954	.949	.943	.938	.932	.927	.921	.915
29.5	.983	.978	.973	.968	.962	.957	.952	.947	.941	.936	.930	.924	.919
29.6	.986	.981	.976	.971	.966	.960	.955	.950	.944	.939	.933	.927	.922
29.7	.990	.985	.980	.974	.969	.964	.959	.953	.948	.942	.937	.931	.925
29.8	.993	.988	.983	.978	.972	.967	.962	.957	.951	.946	.940	.934	.928
29.9	.997	.991	.986	.981	.976	.970	.965	.960	.954	.949	.943	.937	.932
30.0	1.000	.995	.990	.985	.979	.974	.968	.963	.958	.952	.946	.941	.935
30.1	1.003	.998	.993	.988	.983	.977	.972	.966	.961	.955	.950	.944	.938
30.2	1.007	1.002	.996	.991	.986	.980	.975	.970	.964	.959	.953	.947	.941
30.3	1.010	1.005	1.000	.995	.989	.984	.978	.973	.968	.962	.956	.950	.945
30.4	1.014	1.008	1.003	.998	.993	.987	.982	.976	.971	.965	.959	.954	.948
30.5	1.017	1.012	1.006	1.001	.996	.990	.985	.980	.974	.969	.963	.957	.951
30.6	1.020	1.015	1.010	1.005	.999	.994	.988	.983	.977	.972	.966	.960	.954
30.7	1.024	1.018	1.013	1.008	1.003	.997	.992	.986	.981	.975	.969	.963	.957
30.8	1.027	1.022	1.017	1.011	1.006	1.000	.995	.990	.984	.978	.972	.967	.961
30.9	1.031	1.025	1.020	1.015	1.009	1.004	.998	.993	.987	.982	.976	.970	.964
31.0	1.034	1.029	1.023	1.018	1.013	1.007	1.002	.996	.991	.985	.979	.973	.967

The tension of water-vapor for the temperature observed must be found from tables containing these tensions for the different temperatures, such as the following:

TENSION OF AQUEOUS VAPOR IN INCHES OF MERCURY.

Temperature, deg. F.	Inches of Mercury.	Temperature, deg. F.	Inches of Mercury.	Temperature, deg. F.	Inches of Mercury.
40	0.247	57	0.465	74	0.840
41	.257	58	.482	75	.868
42	.267	59	.500	76	.897
43	.277	60	.518	77	.927
44	.288	61	.537	78	.958
45	.299	62	.556	79	.990
46	.311	63	.576	80	1.023
47	.323	64	.596	81	1.057
48	.335	65	.617	82	1.092
49	.348	66	.639	83	1.128
50	.361	67	.661	84	1.165
51	.374	68	.685	85	1.203
52	.388	69	.708	86	1.242
53	.403	70	.733	87	1.282
54	.418	71	.759	88	1.323
55	.433	72	.785	89	1.356
56	.449	73	.812	90	1.401

TENSION OF AQUEOUS VAPOR.

Degrees Centigrade.	Tension in Millimeters of Mercury.	Degrees Centigrade.	Tension in Millimeters of Mercury.	Degrees Centigrade.	Tension in Millimeters of Mercury.
−20	0.927	+ 2.	5.302	6.4	7.193
−10	2.093	+ 2.2	5.378	6.6	7.292
− 2	3.955	+ 2.4	5.454	6.8	7.392
− 1.8	4.016	+ 2.6	5.530	7.	7.492
− 1.6	4.078	+ 2.8	5.608	7.2	7.595
− 1.4	4.140	+ 3.	5.687	7.4	7.699
− 1.2	4.203	+ 3.2	5.767	7.6	7.840
− 1.	4.267	+ 3.4	5.848	7.8	7.910
− 0.8	4.331	+ 3.6	5.930	8.	8.017
− 0.6	4.397	3.8	6.014	8.2	8.126
− 0.4	4.463	4.	6.097	8.4	8.236
− 0.2	4.531	4.2	6.183	8.6	8.347
− 0.	4.600	4.4	6.270	8.8	8.461
+ 0.2	4.667	4.6	6.350	9.	8.574
+ 0.4	4.733	4.8	6.445	9.2	8.690
+ 0.6	4.801	5.	6.534	9.4	8.807
+ 0.8	4.871	5.2	6.625	9.6	8.925
+ 1.	4.940	5.4	6.717	9.8	9.045
+ 1.2	5.011	5.6	6.810	10.	9.165
+ 1.4	5.0[illegible]2	5.8	6.904	10.2	9.288
+ 1.6	5.155	6.	6.998	10.4	9.412
+ 1.8	5.228	6.2	7.095	10.6	9.537

TENSION OF AQUEOUS VAPOR—*Continued.*

Degrees Centigrade.	Tension in Millimeters of Mercury.	Degrees Centigrade.	Tension in Millimeters of Mercury.	Degrees Centigrade.	Tension in Millimeters of Mercury.
10.8	9.665	20.6	18.047	32.	35.359
11.	9.792	20.8	18.271	33.	37.410
11.2	9.923	21.	18.495	34.	39.565
11.4	10.054	21.2	18.724	35.	41.827
11.6	10.187	21.4	18.954	40.	54.906
11.8	10.322	21.6	19.187	45.	71.391
12.	10.457	21.8	19.423	50.	91.982
12.2	10.596	22.	19.659	55.	117.478
12.4	10.734	22.2	19.901	60.	148.791
12.6	10.875	22.4	20.143	65.	186.945
12.8	10.919	22.6	20.389	70.	233.093
13.	11.162	22.8	20.639	75.	288.517
13.2	11.309	23.	20.888	80.	354.643
13.4	11.456	23.2	21.144	85.	433.041
13.6	11.605	23.4	21.400	90.	525.450
13.8	11.757	23.6	21.659	95	633.778
14.	11.908	23.8	21.921	99.	733.21
14.2	12.064	24.	22.184	99.1	738.5
14.4	12.220	24.2	22.453	99.3	741.16
14.6	12.378	24.4	22.723	99.4	743.83
14.8	12.538	24.6	22.996	99.5	746.5
15.	12.699	24.8	23.273	99.6	749.18
15.2	12.864	25.	23.550	99.7	751.87
15.4	13.029	25.2	23.834	99.8	754.57
15.6	13.197	25.4	24.119	99.9	757.28
15.8	13.366	25.6	24.406	100.	760.
16.	13.536	25.8	24.607	100.1	762.73
16.2	13.710	26.	24.988	100.2	765.46
16.4	13.885	26.2	25.288	100.3	768.20
16.6	14.062	26.4	25.88	100.4	771.95
16.8	14.241	26.6	25.891	100.5	773.71
17.	14.421	26.8	26.198	100.6	776.48
17.2	14.605	27.	26.505	100.7	779.26
17.4	14.790	27.2	26.820	100.8	782.04
17.6	14.977	27.4	27.136	100.9	784.83
17.8	15.167	27.6	27.455	101.	787.63
18.	15.357	27.8	27.778	105.	960.41
18.2	15.552	28.	28.101	110.	1075.37
18.4	15.747	28.2	28.433	120.	1491.28
18.6	15.945	28.4	28.765	130.	2030.28
18.8	16.145	28.6	29.101	140.	2717.63
19.	16.346	28.8	29.441	150.	3581.23
19.2	16.552	29.	29.782	160.	4651.62
19.4	16.758	29.2	30.131	170.	5961.66
19.6	16.967	29.4	30.479	180	7546.39
19.8	17.179	29.6	30.833	190.	9442.70
20.	17.391	29.8	31.190	200.	11688.96
20.2	17.608	30.	31.548	220.	17390.
20.4	17.826	31.	33.405	224.7	25 atmos.

The following tables will be useful in calculating the flow of gases in pipes by Pole's formula given in the chapter upon mains.

SQUARE ROOT OF PRESSURE.

Water, Inches.	Square Root.	Water, Inches.	Square Root.	Water, Inches.	Square Root.
0.1	0.3162	1.5	1.2251	2.8	1.6733
0.2	0.4472	1.6	1.2649	2.9	1.7029
0.3	0.5477	1.7	1.3038	3.0	1.7320
0.4	0.6324	1.8	1.3416	3.1	1.7606
0.5	0.7071	1.9	1.3784	3.2	1.7888
0.6	0.7745	2.0	1.4142	3.3	1.8165
0.7	0.8366	2.1	1.4491	3.4	1.8439
0.8	0.8944	2.2	1.4832	3.5	1.8708
0.9	0.9487	2.3	1.5165	3.6	1.8793
1.0	1.0000	2.4	1.5491	3.7	1.9235
1.1	1.0488	2.5	1.5811	3.8	1.9493
1.2	1.0954	2.6	1.6123	3.9	1.9748
1.3	1.1401	2.7	1.6431	4.0	2.0000
1.4	1.1832				

SQUARE ROOT OF THE SPECIFIC GRAVITY OF GAS.

Specific Gravity.	Square Root.	Specific Gravity.	Square Root.	Specific Gravity.	Square Root.	Specific Gravity.	Square Root.
0.350	0.5916	0.440	0.6633	0.530	0.7280	0.620	0.7874
.355	.5958	.445	.6671	.535	.7314	.625	.7905
.360	.6000	.450	.6708	.540	.7348	.630	.7937
.365	.6041	.455	.6745	.545	.7382	.635	.7969
.370	.6083	.460	.6782	.550	.7416	.640	.8000
.375	.6124	.465	.6819	.555	.7449	.645	.8031
.380	.6164	.470	.6856	.560	.7483	.650	.8062
.385	.6205	.475	.6892	.565	.7517	.655	.8093
.390	.6245	.480	.6928	.570	.7549	.660	.8124
.395	.6285	.485	.6964	.575	.7583	.665	.8155
.400	.6325	.490	.7000	.580	.7616	.670	.8185
.405	.6364	.495	.7035	.585	.7648	.675	.8216
.410	.6403	.500	.7071	.590	.7681	.680	.8246
.415	.6442	.505	.7106	.595	.7713	.685	.8276
.420	.6481	.510	.7141	.600	.7746	.690	.8306
.425	.6519	.515	.7176	.605	.7778	.695	.8337
.430	.6557	.520	.7212	.610	.7810	.700	.8367
.435	.6595	.525	.7246	.615	.7842		

C. SPECIFIC GRAVITY.

Specific Gravity Determination.—The relative weight of gases often determines the character of their constituents, whether they contain much or little heavy hydrocarbons or the proportion of hydrogen. Specific gravity is also one of the factors that determine the rate of flow through pipes and occur in Pole's formula. When we say the specific gravity of simple coal-gas is 0.4, we mean

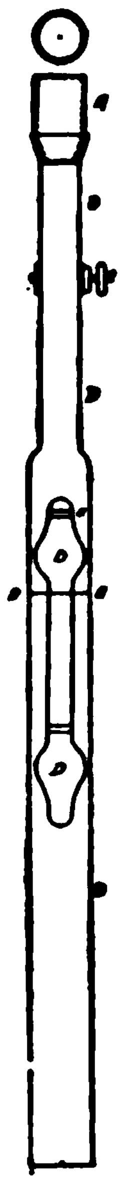


FIG. 69.—Apparatus for Bunsen's Effusion Test of the Specific Gravity of Gas.

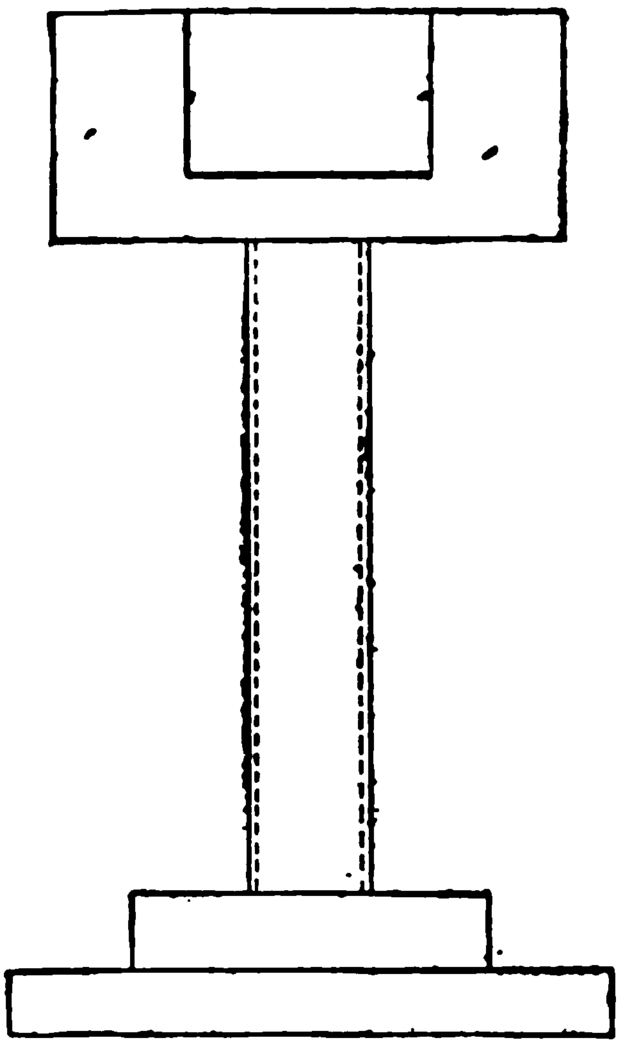


FIG. 70.—Wooden Mercury Trough for Effusion Test.

that it is 0.4 as heavy as the same volume of air under like conditions. The gas balances of Letheby and Dr. F. Lux weigh the gas directly and thus determine its gravity, but the precautions and corrections are too refined for ordinary works operation. The apparatus devised by Professor Bunsen is applicable, however, and accurate as well. It depends upon the property of gases by which the velocity with which they pass through a small orifice depends upon their specific gravity, or, more exactly stated, the densities of two gases are directly proportional to the squares of the times

required for equal volumes under like conditions to pass through the same minute orifice. The apparatus is herewith illustrated and is in two parts, the glass tube for the gas and the stand for the mercury seal, Figs. 69 and 70, as shown by J. A. Butterfield in his work on the Chemistry of Gas Manufacture. A thick-walled glass tube has one end hermetically sealed by a platinum-foil diaphragm pierced at its center by a hole about $\frac{1}{300}$ inch diameter and fitting by a gas-tight ground joint into a long tube *B* about 0.75 in. internal diameter, provided with a stop-cock *C* and an internal float *D*. On the tube a level line *K* is scribed, and two sets of double lines $\frac{1}{16}$ in. apart on the float. Mercury is then poured into the top receptacle of the stand, filling the stem and top up to a line on the glass windows in its side.

The apparatus is now ready for a test. First dry the tube and float thoroughly; see that the mercury is dry and clean, and fill the tube with gas which has been dried by drawing through calcium chloride; insert the open end of the tube into the mercury-bath and into the stem of the stand until the mark *K* coincides with the surface of the mercury. The float, which has been inserted into the tube previously, will float upon the mercury, filling the lower portion of the tube, and rise gradually as the pressure expels the gas through the opened stop-cock and the small aperture in the platinum-foil diaphragm. For more accurate observation a telescope is placed at some distance on a level with the mercury, and as the float appears above the surface of the mercury the appearance of the black scribe lines is watched for, the first one being a warning, and as the second one gets level with the surface of the mercury a stop-watch is started; when the second of the second set of double lines is seen, the watch is stopped and the time elapsed noted. Dried air is then tested in the same manner. If the gas required t minutes and the air t_1 minutes and the density of air be taken as 1, we would then have the proportion

$$\frac{\text{Sp. gr. gas}}{1}=\frac{t^2}{t_1{}^2},$$

from which the specific gravity can be found with sufficient accuracy for ordinary industrial purposes. Several observations should be made of each, however, and the mean used for calculation.

Schilling's Apparatus.—Another apparatus resembling the Bunsen type is often used in determining the specific gravity of a gas. It is known as the Schilling effusion test, using the apparatus shown in Fig. 71. The outer vessel contains water in which is immersed the inner glass tube, weighted at its lower end to keep it immersed and provided at its upper end with two tubes,

one to the left with a valve and the upright one having a 3-way valve with scale having the positions "vent," "off," and "on" marked upon it. The tube also has two scribe marks encircling it. The vertical tube is terminated by a platinum-foil disk perforated by a minute hole. The tube is first raised, air enters through the "vent" position of the cock, which is then turned to "off", the tube placed on the bottom and the cock turned to "on," the air thus being forced through the perforation in the platinum foil by the head of water outside. When the water-level inside rises to the lower scribe mark a stop-watch is started, and stopped immediately when the water reaches the upper mark. The tube is then charged through the side valve with the gas to be tested, and the time in seconds noted as before. Since the velocity of gas passing through such an orifice is proportional to the square root of the density, the densities vary as the squares of the times required for the same volume to pass under like conditions, or, if the gas required t_g or 120 seconds and the air t_a or 180 seconds,

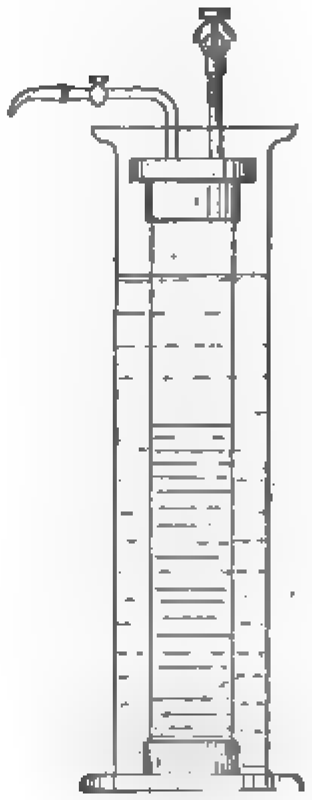


FIG. 71.—Schilling's Effusion Test.

$$\frac{\text{Sp. gr. gas}}{\text{Sp. gr. air}=1}=\frac{t_a^2}{t_g^2}=\frac{(180)^2}{(120)^2}=0.44.$$

Dr. Letheby devised a more accurate piece of apparatus for the same purpose, consisting of a glass globe having extensions and valves above and below. The upper end, as shown in Fig. 72, is terminated by a tube surmounted by a small gas-burner and containing a sensitive thermometer. The lower end is attached to a gas-jet and gas allowed to flow through until all the air is expelled, when the cock is closed and the upper cock an instant later. The thermometer is then read and the globe weighed complete in a sensitive balance in a dry atmosphere. Previously it had been weighed when filled with air and the weight of air contained corrected to 60 deg. F. and 30 in. barometric pressure; suppose it to have been 31 grains. Suppose the temperature of the gas to have been found to be 56 deg. F., the barometric pressure 30.3 in., and its weight, over the weight when holding a vacuum, found to be 15 grains. The correction for temperature and pressure is 0.98, making the corrected weight of the gas 14.7 at 60 deg. and 30 in. Then $14.7 \div 31 = 0.47$, the specific gravity desired.

The volume of this globe can be readily calculated when once the weight of air contained is accurately determined. Since 1 cu. ft. of moist air weighs 532.4 grains and of dry air 535.9 grains, 100 cu. in. of moist air will weigh 30.81 grains, which will contain 0.336 grain of moisture, making the weight of 100 cu. in. to be $30.81-0.336=30.474$ grains. Suppose the given globe was found to contain 30.964 grains of air at 60 deg. and 30 in.; divide this by 30.474 and the resultant volume of the globe will be 100.5 cu. in. As found in the test the globe contained 15 grains of gas; then $(15\times100)\div100.5=14.92$ grains will be the weight of gas it contained for 100 cu. in. capacity.

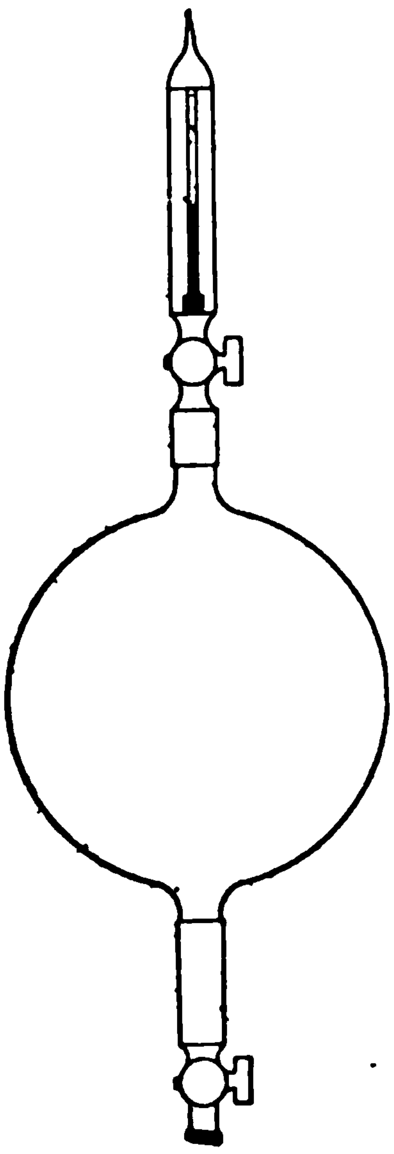


Fig. 72.— Letheby Globe for Weighing Gases.

Greville Williams described a method for determining the specific gravity of gas in the Transactions of the Gas Institute for 1882. He dries the gas and air before testing, although this is not essential for the method. Balances used in specific gravity determinations must be of extreme accuracy, weighing to one-tenth milligram when the globe need not be over 400 c.c. capacity. The globe is not exhausted and temperature and barometer corrections are avoided by selecting a day when the barometer is steady and keeping the gas and air at the same temperature by means of a gas-stove. The air must first be freed from CO_2 and moisture by passing through KOH, then H_2SO_4, then soda-lime and calcium chloride. The air is drawn through the globe until all trace of other gases is removed, indicated by the globe remaining constant in weight, the cocks are closed, the globe carefully wiped with clean chamois leather and hung by platinum wire to the balance-arm, balanced, and the weight noted; after hanging 5 minutes the weight is noted again. The gas is then passed through the globe for an hour, after first being dried by tubes of calcium chloride, the cocks closed, the one on the supply-pipe end first, and the globe again weighed. Gas may be thus weighed continuously, as long as the barometer and thermometer remain constant. Some tests on hydrogen showed a deviation of 0.0014 from its theoretical gravity of 0.0693. Bunsen obtained a value of 0.079, or an error of 0.01, by this method.

The specific gravity can now be calculated by this formula:

$$D=\frac{Vn_t-P}{Vn_t},$$

where V = capacity of globe in cubic centimeters;
P = difference between the weights of globe with air and with gas, grammes;
n = weight of 1 c.c. of air at T deg. C.;
D = specific gravity by experiment.

The advantage is, of course, the doing away with producing a vacuum in the globe.

Dr. Lux invented a balance which goes by his name and is shown in Fig. 73. The globe is at one end of a balance-arm, the

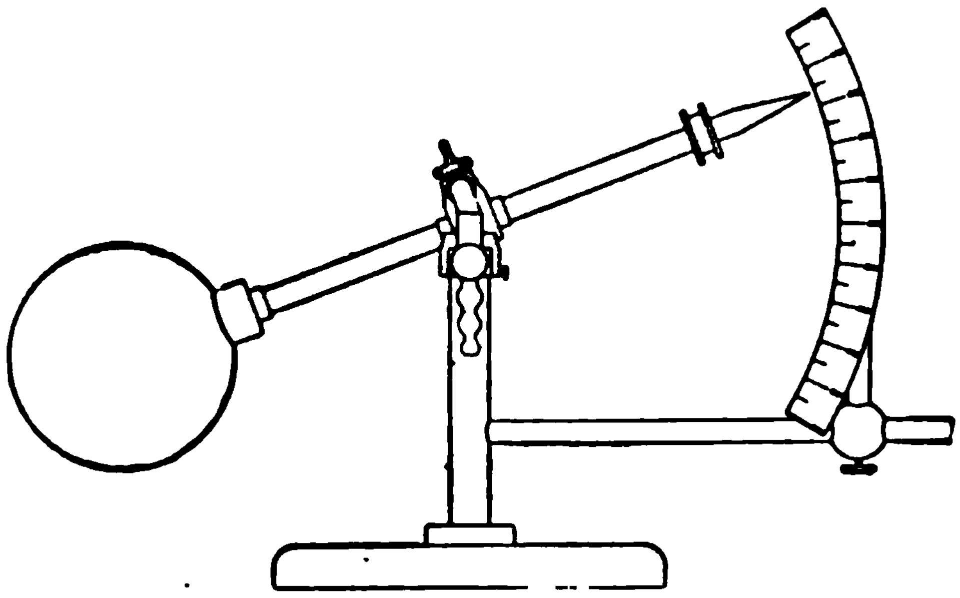


FIG. 73.—Lux Gas-balance.

gas connections dipping into mercury, and the specific gravity is read directly on the scale at the other end, uncorrected for atmospheric conditions. Thus air will be 1 on the scale, hydrogen at 0.07, etc. The corrections to be made are for pressure and temperature. For every millimeter at which the barometer stands above or below 760 mm. there is added or deducted 0.0007 from the reading on the scale. For every degree C. at which the thermometer is above or below 15 deg. C. deduct or add 0.002 to the scale reading. The apparatus requires very careful adjustment, but affords a ready means for determining specific gravity.

Specific Gravity of Oils.—This can best be found by a specific-gravity bottle, or a carefully graduated hydrometer, the oil being either at 60 deg. F. or 39.1 deg. F. Take a glass-stoppered specific-gravity bottle, weigh it, fill it up to a mark with recently boiled distilled water at 60 deg. or 39.1 deg. F., weigh again, dry with alcohol, fill to the mark on the neck with the spirit or oil to be tested (at 60 deg. or 39.1 deg.), weigh again. Then the weight of oil divided by the weight of the water will equal the specific gravity. The coefficient of expansion of petroleum oils is about 0.0036 per deg. F. or 0.0065 per deg. C. To find the weight of a cubic foot of oil, multiply its specific gravity by 62.425, the weight of a cubic foot of water. Oils are usually tested in degrees Baumé,

the following table therefore being useful in converting Baumé degrees into specific gravity.

CONVERSION OF HYDROMETER DEGREES INTO SPECIFIC GRAVITY.

Degrees Baumé.	Specific Gravity, Water = 1.5.	Pounds per Gallon.	Degrees Baumé.	Specific Gravity, Water = 1.	Pounds per Gallon.
10	1.0000	8.33	49	0.7821	6.52
11	.9929	8.27	50	.7777	6.48
12	.9859	8.21	51	.7734	6.44
13	.9790	8.16	52	.7692	6.41
14	.9722	8.10	53	.7650	6.37
15	.9655	8.04	54	.7608	6.34
16	.9589	7.99	55	.7567	6.30
17	.9523	7.93	56	.7526	6.27
18	.9459	7.88	57	.7486	6.24
19	.9395	7.83	58	.7446	6.20
20	.9333	7.78	59	.7407	6.17
21	.9271	7.72	60	.7368	6.14
22	.9210	7.67	61	.7329	6.11
23	.9150	7.62	62	.7290	6.07
24	.9090	7.57	63	.7253	6.04
25	.9032	7.53	64	.7216	6.01
26	.8974	7.48	65	.7179	5.98
27	.8917	7.43	66	.7142	5.95
28	.8860	7.38	67	.7106	5.92
29	.8805	7.34	68	.7070	5.89
30	.8750	7.29	69	.7035	5.86
31	.8695	7.24	70	.7000	5.83
32	.8641	7.20	71	.6990	5.80
33	.8588	7.15	72	.6956	5.78
34	.8536	7.11	73	.6923	5.75
35	.8484	7.07	74	.6889	5.72
36	.8433	7.03	75	.6829	5.69
37	.8383	6.98	76	.6823	5.66
38	.8333	6.94	77	.6789	5.63
39	.8284	6.90	78	.6756	5.60
40	.8235	6.86	79	.6722	5.58
41	.8187	6.82	80	.6666	5.55
42	.8139	6.78	81	.6656	5.52
43	.8092	6.74	82	.6619	5.50
44	.8045	6.70	83	.6583	5.48
45	.8000	6.66	84	.6547	5.45
46	.7954	6.63	85	.6511	5.42
47	.7909	6.59	90	.6363	5.30
48	.7865	6.55	95	.6222	5.18

D. SPECIFIC HEAT.

Specific Heat Defined.—This term denotes the amount of heat, expressed in heat-units, which is required to raise by 1° the temperature of unit weight of a substance. Since a heat-unit is the amount of heat required to raise by 1° the temperature of unit weight of water, the specific heat of a substance is the ratio between the amount of heat needed to raise by 1° the temperature of unit weight of the substance and the amount of heat required to raise by 1° the temperature of unit weight of water. If the unit of weight is the pound avoirdupois, and the temperature is measured in Fahrenheit degrees, the specific heat is expressed in British thermal units, while if the unit of weight is the kilogram, and the temperature is measured in centigrade degrees, the specific heat is expressed in calories. It is expressed by the same number in each case. More heat is required to raise the temperature of unit weight of water a given amount than is needed to raise by the same amount the temperature of unit weight of any other substance, with the exception of hydrogen; therefore, with this exception, the specific heats of all substances are less than 1.

The amount of heat required to raise by 1° the temperature of a body which is free to expand, or, as it is said, is kept under constant pressure, is not the same as the amount required to produce the same change in temperature in the body if it is kept at a constant volume. For every substance there are, therefore, two values for the specific heat, one for constant pressure and one for constant volume. There is also what is termed specific heat by volume, which is the amount of heat, expressed in heat-units, required to raise by 1° the temperature of unit volume of a substance. But when the term "specific heat" is used without any qualification, as in the statement "the specific heat of nitrogen is 0.244," it refers to specific heat by weight and at constant pressure.

The relative illuminating value of the different hydrocarbons contained in water-gas has been stated as follows when the gas is tested in a burner consuming it at 5 cu. ft. per hour:

Benzene........................	C_6H_6	349.0
Ethane........................	C_2H_6	35.0
Ethylene........................	C_2H_4	68.5
Methane........................	CH_4	5.0

CALCULATING MEAN SPECIFIC HEAT IN A GAS.

Constituent.	Per Cent by Volume.	Weight of 1 Cu. Ft. in Pounds.	Weight of Constituent in Pounds.	Specific Heats.	Sp. H. × Wt. × Vol.	Authority for Value of Sp. H.
Benzol....	1.00	0.20640	0.20640	1.187	0.2450	Wullner.
C_2H_4.....	3.75	0.07410	0.27787	1.245	0.3460	"
CO......	8.04	0.7407	0.59552	1.403	0.8355	"
H.......	47.04	0.00530	0.24931	1.396	0.3580	Regnault.
CH_4......	36.02	0.04234	1.52508	1.319	2.0115	Masson.
CO_2......	1.60	0.11637	0.18619	1.300	0.2420	"
O........	0.39	0.08463	0.03300	1.405	0.0464	Regnault.
N.......	2.15	0.07429	0.16046	1.405	0.2255	"
	100.00	....	3.22383	......	4.3099	

$\frac{4.3099}{3.2283}=1.337$, the value of the mean specific heat for the above gas.

TABLE OF MEAN SPECIFIC HEATS AT CONSTANT PRESSURE.
(In B.t.u. per Pound.)

Degrees Fahrenheit.	Carbon Dioxide.	Water-vapor.	Nitrogen.	Oxygen.
212	0.201	0.446	0.244	0.214
392	0.210	0.462	0.249	0.218
572	0.219	0.478	0.253	0.222
752	0.227	0.494	0.257	0.225
932	0.236	0.510	0.262	0.229
1112	0.245	0.526	0.266	0.233
1292	0.254	0.541	0.270	0.237
1472	0.263	0.557	0.275	0.241
1652	0.271	0.573	0.279	0.244
1832	0.280	0.589	0.284	0.248
2012	0.289	0.605	0.288	0.252
2192	0.298	0.621	0.292	0.256
2372	0.307	0.637	0.297	0.260
2552	0.315	0.652	0.301	0.264
2732	0.324	0.668	0.305	0.267
2912	0.333	0.684	0.310	0.271
3092	0.342	0.700	0.314	0.275
3272	0.351	0.716	0.318	0.279
3452	0.360	0.732	0.323	0.282
3632	0.368	0.748	0.327	0.286
3812	0.377	0.764	0.331	0.290
3992	0.385	0.780	0.336	0.294
4172	0.394	0.796	0.340	0.298
4352	0.403	0.812	0.344	0.301
4532	0.412	0.828	0.349	0.305

Inaccuracies in the experimental data on which this table is based render it useless to attempt to interpolate more closely than to ninety degrees.

SPECIFIC HEATS AT CONSTANT PRESSURE.

Air	0.2375
Oxygen	0.2175
Hydrogen	3.4090
Nitrogen	0.2438
Carbon dioxide, CO_2	0.2170
Carbon monoxide, CO	0.2479
Olefiant gas (ethylene), C_2H_4	0.4040
Marsh gas (methane), CH_4	0.5929
Blast-furnace gas	0.2280
Chimney gases from boilers	0.2400
Steam, superheated	0.4805

"VOLUMETRIC" SPECIFIC HEATS.

Air, oxygen, carbon monoxide, hydrogen, and nitrogen = 0.019.

Carbon dioxide and marsh gas = 0.027.

Producer gas = 0.019.

Volumetric specific heat is the quantity of heat required to raise the temperature of 1 cubic foot 1 degree from 32° to 33° F.

SPECIFIC HEAT OF SOLIDS AND LIQUIDS.

(Water = 1.)

Substance.	Specific Heat.	Substance.	Specific Heat.
Acetic acid	0.6589	Lead	0.0314
Alcohol (sp. gr. 793)	0.622	Lime, burned	0.217
Aluminium	0.2143	Lithium	0.9408
Antim ny, cast	0.05077	Magnesium	0.2499
Arsenic	0.0814	Manganese	0.1217
Beeswax	0.45	Marble, white	0.21585
Benzine	0.3952	Mercury	0.03332
Birch	0.48	Nickel	0.10863
Bismuth	0.03084	Oil, olive	0.3096
Brass	0.09391	Oil, sweet	0.31
Brick, common	0.2	Oil of turpentine	0.472
Brick, fire	0.22	Palladium	0.05928
Cadmium	0.05669	Phosphorus	0.18949
Chalk, white	0.21485	Pine	0.65
Charcoal, animal, calcined	0.26085	Platinum	0.03243
Charcoal, wood	0.24111	Potassium	0.1606
Clay, white, burned	0.185	Selenium	0.07616
Coal	0.2777	Silicon, crystallized	0.1774
Cobalt	0.10696	Silicon, fused	0.175
Copper	0.09215	Silver	0.05701
Diamond	0.14687	Sodium	0.2934
Ether	0.5207	Spermaceti	0.32
Glass	0.19768	Steel	0.1175
Gold	0.03244	Sulphur	0.20259
Graphite	0.20187	Sulphuric acid	0.222
Ice	0.504	Tellurium	0.4737
Iodine	0.05412	Thallium	0.0336
Iron, cast	0.12983	Tin	0.05695
Iron, wrought	0.11379	Zinc	0.09555

SPECIFIC HEAT OF GASES AND VAPORS.

		Specific Heat of Equal Weights.	Specific Heat of Equal Volumes.	Specific Heat of Constant Volumes.
Simple Gases	Air	0.2374	0.2374	0.1687
	Oxygen	0.2175	0.2405	0.1559
	Nitrogen	0.2438	0.2370	0.1740
	Hydrogen	3.4090	0.2359	2.4096
	Chlorine	0.1210	0.2962	
	B.omine	0.0555	0.3040	
Compound gases	Binoxide of nitrogen	0.2315	0.2406	
	Carbonic oxide	0.2450	0.2370	0.1768
	Carbonic acid	0.2163	0.3307	0.1714
	Sulphureted hydrogen	0.2432	0.2857	
	Sulphurous an ydride	0.1553	0.3414	0.1246
	Hydrochloric acid	0.1845	0.2333	
	Nitrous oxide	0.2262	0.3447	
	Nitric oxide	0.2317	0.2406	
	Ammonia	0.5083	0.2966	
	Marsh gas	0.5929	0.3277	0.4683
	Olefiant gas (ethylene)	0.4040	0.4106	
Vapors	Water (steam)	0.4805	0.2984	0.3337
	Ether	0.4810	1.2296	0.3411
	Chloroform	0.1567	0.6461	
	Alcohol	0.4534	0.7171	0.3200
	Turpentine	0.5061	2.3776	
	Bisulphide of carbon	0.1570	0.4140	
	Benzole	0.3754	1.0114	
	Acetone	0.4125	0.8244	

The following figures are given by D. K. Clark in his treatise:

Substance.	Specific Heat.	Substance.	Specific Heat.
Ice	0.504	Brickwork, masonry	0.200
Water at 32° F.	1.000	Coal	0.2411
Gaseous steam	0.475	Anthracite	0.2017
Saturated steam	0.305	Oak wood	0.570
Mercury	0.0333	Fir wood	0.650
Sulphuric ether	(0.715) 0.5200	Oxygen (constant wt. and vol.)	0.1559
Alcohol	0.6588	Air (const. pres.)	0.2377
Lead	0.0314	Air (const. wt. and vol.)	0.1688
Gold	0.0324	Nitrogen (const. wt. and vol.)	0.1740
Tin	0.0566	Hydrogen (const. wt. and vol.)	2.4096
Silver	0.0570	Carbonic oxide (const. wt. and vol.)	0.1768
Brass	0.0939	Carbonic acid (const. wt. and vol.)	0.1714
Copper	0.0951		
Zinc	0.0956		
Nickel	0.1086		
Wrought iron	0.1138 to 0.1255		
Steel	0.1165 to 0.1185		
Cast iron	0.1298		

E. CALORIFIC VALUE.

Calculating Calorific Power.—Since results are stated in B.t.u. per cu. ft. of the gas investigated, and the analysis usually gives percentage by volume, it is often convenient to use the volume values for the calorific power of the constituents of a complex gas. Thomas B. Stillman in his "Engineering Chemistry," p. 259, gives the following values, which are here tabulated for more convenient reference.

Gas.	Calories per Kilogram.	B.t.u. per Pound.	B.t.u. per Cubic Foot, 0° C., 760 mm.
H, hydrogen	34,500	62,100	348
CO, carbonic oxide	2,487	4,476	349
CH_4, methane	13,245	23,851	1,065
C_2H_2, acetylene	11,925	21,465	1,555
C_2H_4, ethylene	11,900	21,440	1,673
C_2H_6, ethane	12,350	22,230	1,858
Illuminants of gas	....	....	2,000
C_3H_8, propane	12,028	21,650	2,654
C_3H_6, propylene	11,900	21,420	2,509
C_4H_{10} butane	11,850	21,330	3,477
C_3H_{12}, pentane	11,770	21,186	4,250
C_6H_{14}, sextane	11,620	20,916	5,012
C_6H_6, benzene	10,250	18,450	4,010
$C_{10}H_8$, naphthalene	9,620	17,316	6,176

Combustion is generally affected through the addition of air to combustible gases, the composition of air being:

	Per Cent by Weight.	Per Cent by Volume.	Ratio.
O, oxygen	23.134	20.92	1.00
N, nitrogen	76.866	79.08	3.78

Having the composition by volume of a gas, its calorific power will equal the sum of the calorific powers of its constituents calculated as shown in the following example:

Constituents.	Proportion by Volume.		B.t.u. per Cu. Ft.		Total B.t.u. in Gas.
CO	0.280	×	349.5	=	97.86
CO_2	0.038				
C_2H_4, etc., illuminants	0.146	×	2000.0	=	292.00
H	0.356	×	348.0	=	123.88
CH_4	0.167	×	1065.0	=	177.85
	1.087		Total	=	691.59

It is necessary that the volume per cents be reduced to 0 deg. C. (32 deg. F.) and 760 mm. barometer, which are the standard conditions for a gas; also that exactly the proper proportion of oxygen be used and the gases and water-vapor formed be reduced to 0 deg. C. and 760 mm. pressure, the basis upon which the values in the table of calorific values of gases are calculated. Generally the temperature assumed in works conditions is 60 deg. F. and atmospheric pressure, combustion taking place in air instead of oxygen. Therefore the heat added by the air and gas and the heat escaping in the products of combustion must be considered in connection with the B.t.u. in one cubic foot of gas consumed under standard conditions. Thus one cubic foot of hydrogen at 32 deg. F. burned, and all the heat conserved at 32 deg. F., will generate 348 B.t.u.; on the contrary if the hydrogen at 60 deg. F. burns in such a way that its products escape, containing their heat unutilized, at 328 deg. F., then the calorific power will be only 264 B.t.u.; in the same limits the B.t.u. of CO would be 315 B.t.u., CH_4 would have 853 B.t.u., and the illuminants would have 1700 B.t.u. utilized per cu. ft. The example of gas previously taken would, under these limits of 60 deg. to 328 deg. F., have a calorific power of only 552.83 B.t.u. It is therefore of much importance in using such values to know whether they are reduced to standard conditions, or, if not, what the conditions are under which the result given was calculated.

THE JUNKER GAS-CALORIMETER.

The increasing use of gas for fuel purposes is making the heat-producing value of relatively greater importance than the candle power as determined on photometers. Although the heat value of a gas can be estimated by calculation from an analysis, yet the direct determination, in an apparatus designed to burn the gas completely and collect the heat in such a manner as to measure it, is more rapid and direct. Such an apparatus is called a calorimeter, of which the bomb type is the most accurate, but the Junker type the more convenient and most used. Fig. 74 shows the arrangement of this apparatus, complete. The gas first passes through the test-meter provided with a thermometer for taking the temperature of the gas before combustion, a pressure-regulator, Figs. 75 and 76, to insure constant pressure at the burner, a burner removably attached and adapted to regulate the air supply, as shown by the detail illustration, Fig. 78, a calorimeter vessel in which the gas is burned and the heat absorbed by circulating water, an elevated water supply flowing under constant head, and a vessel for measuring the water passing through it.

The details of the calorimeter body are illustrated in Fig. 77 (see next page), showing how the consumed gases travel up the combustion-

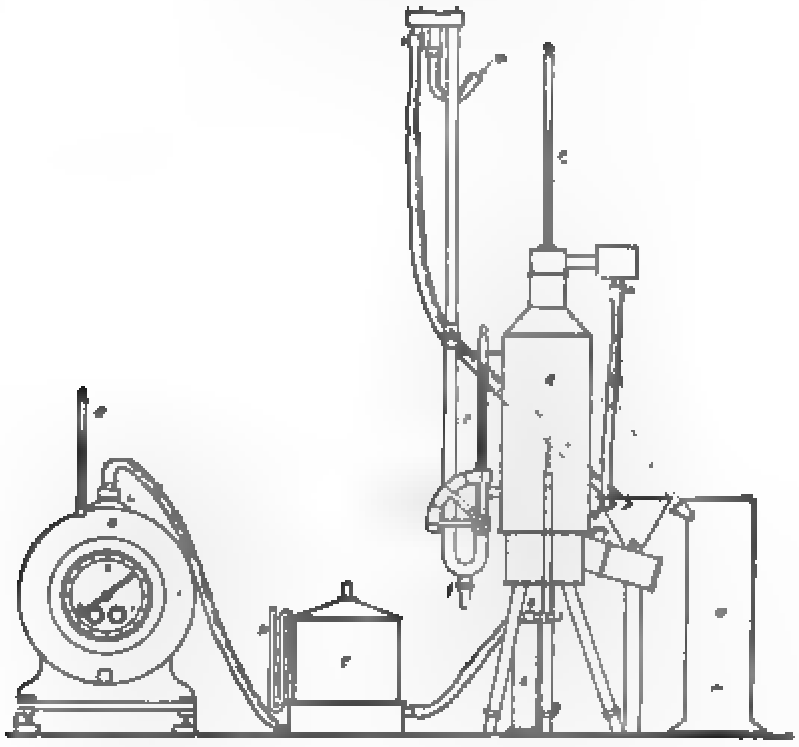


FIG. 74.—General Arrangement of Junker Calorimeter.

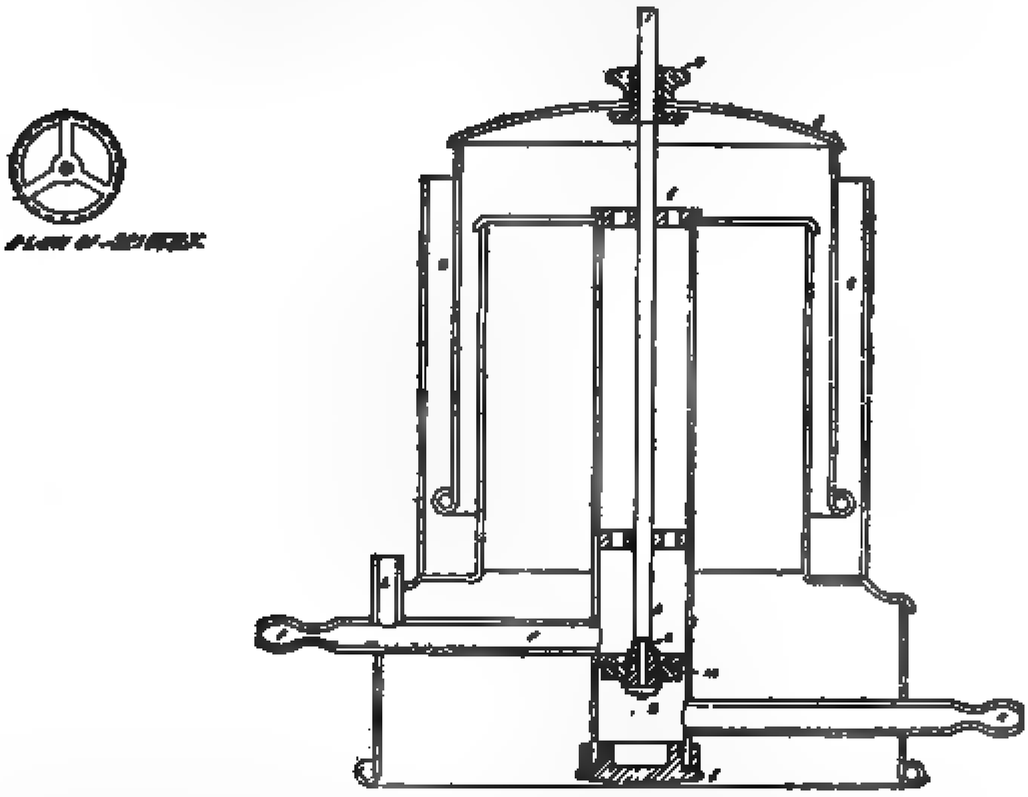


FIG. 75.—Section of Pressure-regulator, *C*.

chamber and pass down through tubes surrounded by water and out into the air of the room at the lower opening. The heat that enters the apparatus is contained in the form of temperature in the

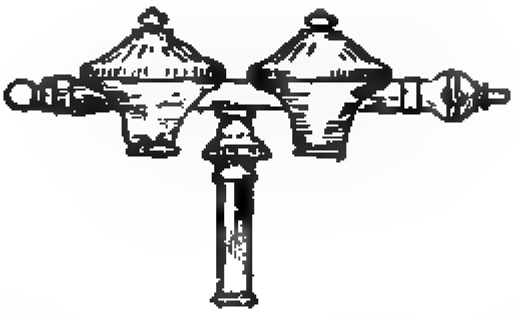


FIG. 76.—Pressure-regulator without Liquid Seal.

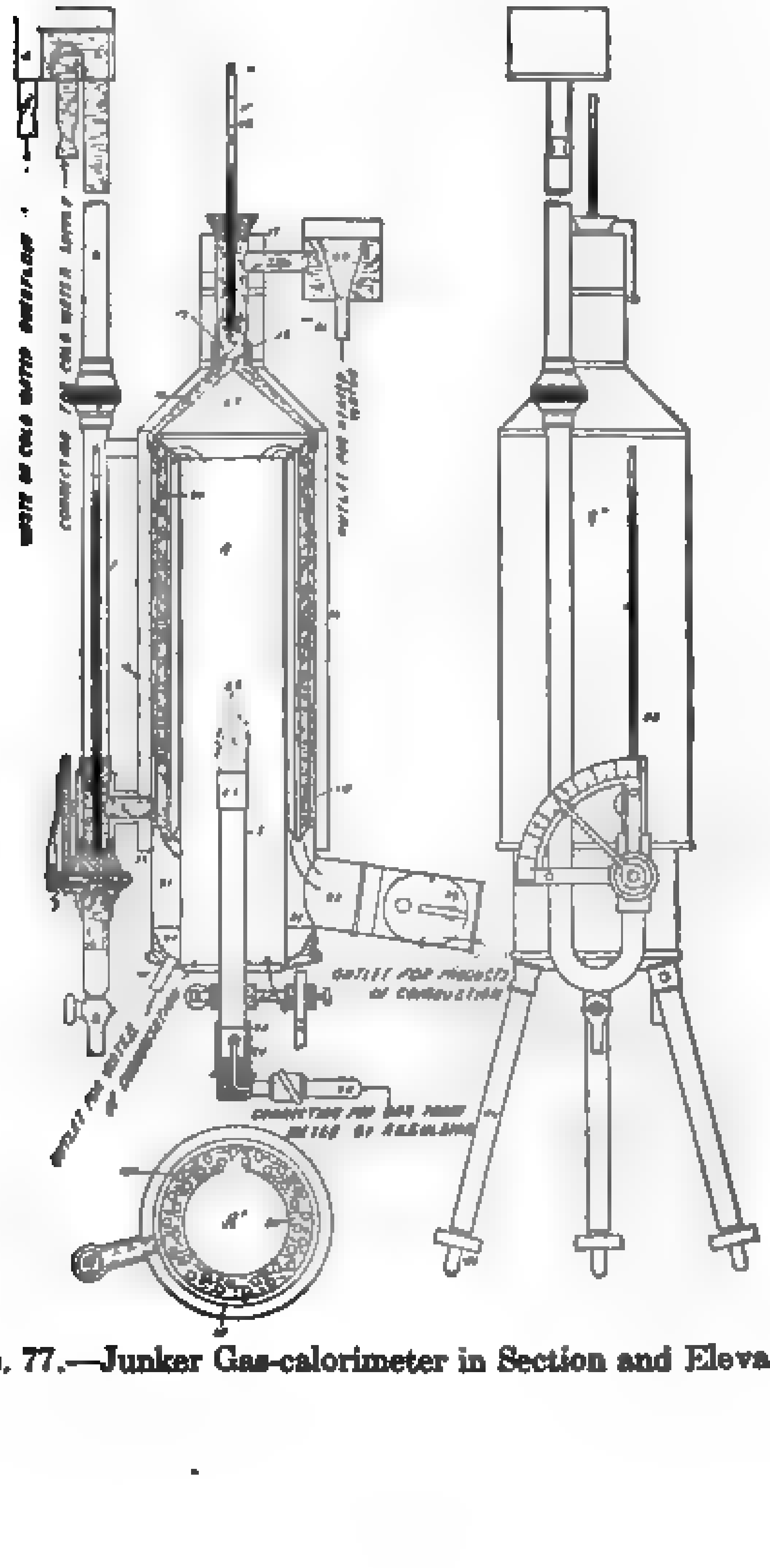


FIG. 77.—Junker Gas-calorimeter in Section and Elevation.

gas, air, and water entering it, and in combustible constituents in the gas; thermometers are therefore necessary to test the temperature of the air of the room, of the gas supplied, and of the water entering the apparatus. The heat escaping from it is contained in the products of combustion (water of condensation and fuel-gas) and the water collected, which requires two more thermometers. The air-jacket prevents radiation of heat, and all essential provisions are made to keep heat from escaping unrecorded. In construction the apparatus differs slightly according to the ideas of different makers, but the principles of operation remain the same.

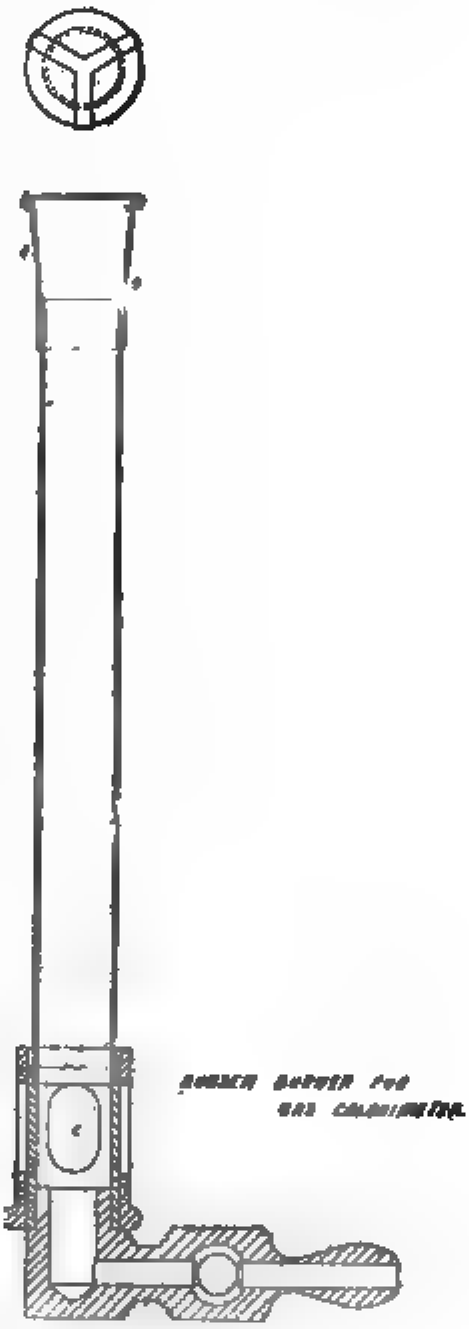


Fig. 78.—Burner of Junker's Calorimeter.

The apparatus being set up and properly connected by rubber tubes, water is run into the elevated tank and through the apparatus into the drain at J until the flow is steady, when the valve can be set with its indicator on the scale so that about 400 c.c. of water will flow into the graduate D per minute; there should be a constant but slight overflow through the tube b, which is regulated by a valve on the supply-tube a. The water level in the wet-test meter in the governor and U tube H are of course looked after and more water added if necessary. Remove the Bunsen burner I, Fig. 77, to prevent explosion, turn on the gas, light it, adjust the air-shutter, and replace, adjusting the gas-supply to keep the difference in temperature between ingoing and outgoing water about 10 deg. C., during which time about 3 liters of water are passing. The rate of gas flow will be governed by the flame, which should be of proper size to give out about 1200 calories per hour. Variation in the quality of gas therefore will require more consumption for the lean gases and less for rich gases, the latter requiring also a considerable air supply and the lean gases very little, if any; the flue damper being adjusted accordingly.

Having the apparatus in normal operation, a test is begun by taking the temperatures of the air in the room near the calorimeter, the temperature of the gas going through the meter (*G*), and the temperature of the gases of combustion in the flue at *J*. Then watch the meter-hand until it is at a convenient starting-point, immediately switch the outlet-tube from the drain-funnel to the empty graduate, note the time, temperature of water entering (*F*) and leaving (*F′*) as quickly as possible to the hundredth part of a degree. A stop-watch is very convenient for this purpose, one that has a second and a minute hand, and reading-glasses on the thermometers facilitate that part of the work. An observation is completed when the water collected reaches a little over 1700 c.c. in the graduate, when the readings are taken as at the start, the time being noted when the outlet-tube is removed from the graduate and the meter read. The temperature of inlet and outlet water is observed about every half-minute.

The formula for calculating the calorific value of a gas from these observations, given in metric units, is as follows (see Bates on Calorimetry, p. 25):

$$C=\frac{1000W(T_{OW}-T_{IW})+K(T_{IW}-T_G)+K'(T_{EG}-T_{IW})}{G},$$

where C = calories per cubic meter;
G = liters of gas consumed as shown by the meter;
T_{OW} = temperature of outlet water, thermometer F';
T_{IW} = temperature of inlet water, thermometer F;
T_G = temperature of the gas at meter, thermometer G;
T_{EG} = temperature of escaping gases, thermometer J;
W = water collected in graduate D in liters;
K, K' = constants calculated from the specific heats of the average quality of gases by Bates as follows, in calories:

	K	K'
Natural gas	0.011	3.432
Coal-gas	0.010	2.466
Water-gas	0.009	1.353
Producer-gas	0.0089	0.470

In case the heat value is desired under standard conditions, say of 0 deg. C., where the gas is more dense and the calorific value naturally higher, the value of C is multiplied by $\frac{273+T_G}{273}$. There is another correction not yet mentioned, the heat carried off by the moisture condensed from the water vapor formed during com-

bustion, which escapes from tube No. 35 shown in the section. When 1 kilogram of hydrogen burns to form 9 kg. of water vapor, at 100 deg. C. (212 deg. Fah.) it generates 28732 calories, but if this vapor is brought to 0 deg. C. the heat given up is 34462, the difference being due to the latent heat of the steam and in the water formed. As calorimeter results may vary as much as 10 per cent from this cause, it is always well to state whether the calories found are gross or net. The correction is easy, consisting in deducting from the calories found by the formula 0.636 calories per cubic centimeter of water of condensation collected; as less than 1 c.c. of water is thus collected per liter of gas, it is generally measured after the series of tests.

Example. In a 5.5-minute test by Bates in which three readings were made on the gases and twelve on the water, the averages were found to be: $T_G=25.6$ deg., $T_{EG}=20$ deg., $T_{IW}=14.739$ deg., $T_{OW}=29.76$ deg., $G=4.5$ liters, $W=1.74$ liters. Substituting these values in the formula we get

$$C=\frac{1.740(29.76-14.739)1000+0.01(14.739-25.6)+2.466(20-14.739)}{4.5}$$

$$=5820.985 \text{ calories per cubic meter.}$$

Applying now the temperature correction we find that at 0 deg. C. the calorific value will be

$$5820.985\left(\frac{273+25.6}{273}\right)=6344.8736 \text{ calories.}$$

To reduce this to B.t.u. per cu. ft. multiply by 0.11236, thus:

$$6344.8736\times0.11236=712.9099 \text{ B.t.u.}$$

Liquid Fuels.—This instrument can also be used to test liquid fuels, such as oils, alcohol, turpentine, naphtha, kerosene, gasoline distillate or petroleum, the arrangement of apparatus being shown in Fig. 79. Instead of the gas-meter, governor, and burner are substituted scales upon one arm of which is suspended a burner suitable for burning the liquid fuel. At the beginning of the test the lamp is lighted and inserted, the scales are balanced with the lamp end slightly low, the water supply is adjusted as with gas, and as the beam comes to a perfect balance, the water-outlet is switched into the empty graduate and readings taken as with gas. Place a weight on the weight-pan equal to the quan-

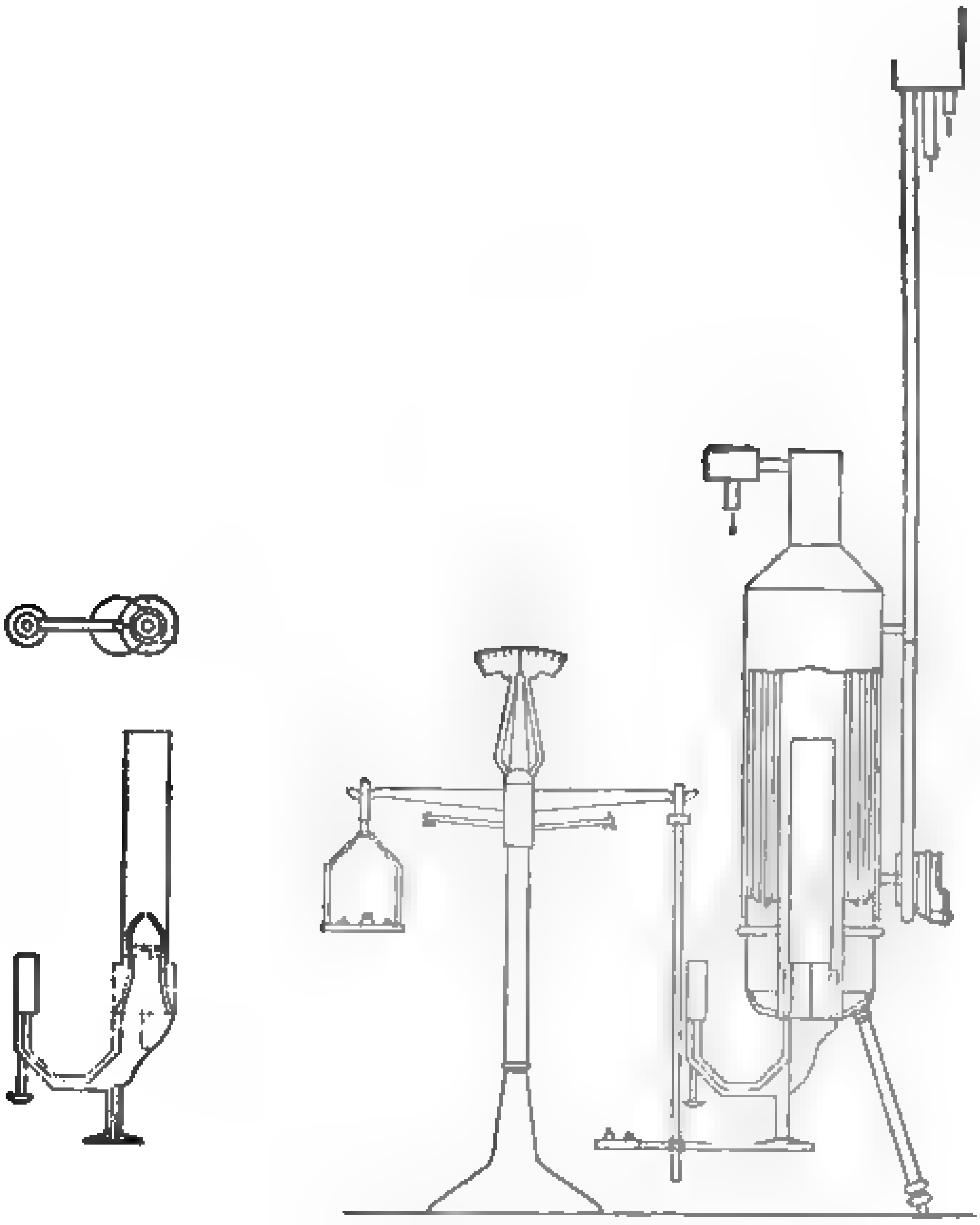


Fig. 79.—Junker's Calorimeter Adapted for Liquid Fuels.

tity it is desired to test, and as the beam again comes to equilibrium take final readings quickly. The calorific value is then calculated by this formula:

$$C = \frac{W(T_{OW} - T_{IW})1000000}{G_0},$$

where C = calories per kilogram;
G_0 = weight of fuel burned in milligrams;

the other terms being the same as before. Calories per kilogram can be reduced to B.t.u. per pound by multiplying the calories by 1.8.

THE SIMMANCE-ABADY GAS-CALORIMETER.

With the purpose in mind of devising a calorimeter by which quick tests could be made with the greatest chance of accuracy,

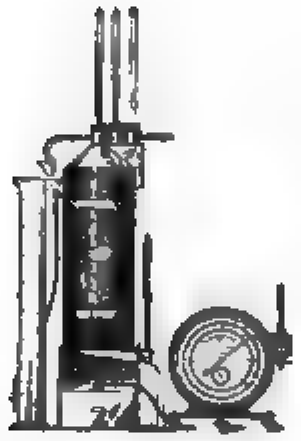


FIG. 80.—Arrangement of Simmance-Abady Gas-calorimeter with Thermometers Used.

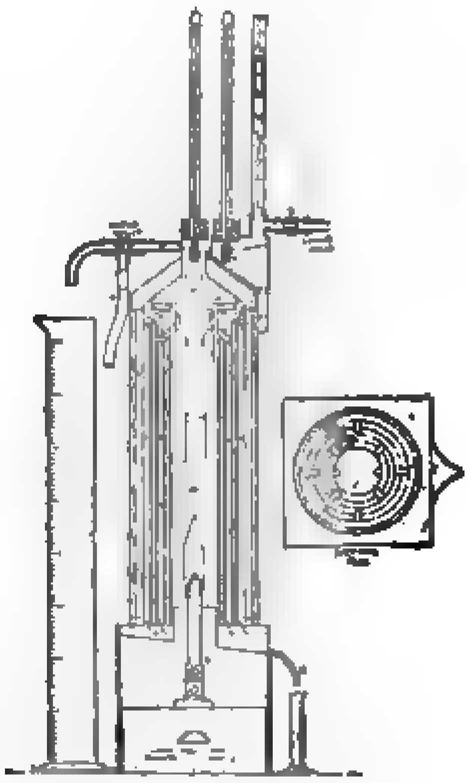


FIG. 81.—Sections of Simmance-Abady Calorimeter.

Messrs. Simmance and Abady, two consulting chemists of London, invented the calorimeter which bears their names. It is of the

Junker type with distinct improvements. Short and rapid tests may be made with it, taking but a few seconds by reason of the convenient arrangement of instruments to be read, and but a minute to make a complete test for calorific power of a gas. The rapidity at which gases can be burned can be regulated, the relative area exposed to the burning gases is increased, the thermometers are arranged together and with magnified scales for quick reading, the head of water entering can be determined with positive accuracy, and every effort made to secure an instrument which combines quickness with accuracy. In the accompanying illustrations the water-inlet is shown at *A*, cock at *B*, whence the water rises in the tube *C* to a height equal to its pressure, flows around the thermometer *D* in centigrade degrees divided into tenths, thence through annular shells *E*, down tubes *F*, up through tubes *G*, past the baffle-plate into the upper space *H* containing a thermometer *J*, and escapes at *K* either through the waste-pipe *L*, or into the graduated measure *M* of 1000 c.c. capacity in 2 c.c. graduations. The consumed gas rises through *N* to *O*, where the temperature is low enough for the water-vapor formed to condense, falls down through the passages *P* to the chamber below, which is about the temperature of the air entering the burner chamber, and escapes through a shutter with thermometer at *Q*, the condensed moisture being collected at *R*. For every cubic centimeter of this condensed vapor of water thus collected per cubic foot of gas burned 0.6 calorie must be deducted from the gross calories per cubic foot, or 2.382 B.t.u. per cubic centimeter per cubic foot of gas burned must be deducted from the gross B.t.u. per cubic foot. In setting up the calorimeter the instructions of the makers should be followed closely, being very careful in handling all its parts. The gas supply must be under uniform pressure.

The operation is similar to that of the Junker. The water supply must be under uniform pressure, preferably from an elevated tank provided with a ball valve, as indicated by the height of the float or water in the tube *C*. Light the gas-burner outside and put it in place, adjusting the flow of gas to get the best combustion results, adjust the damper at *G* so that the products of combustion are of the same temperature as the entering water, take the temperature of the gas and air of the laboratory, and the barometric reading. As the meter-hand passes zero mark turn the outlet running water into the graduate *M*, and as the hand passes a determined point, say 12, switch the water back into the waste-drain; repeat the test twice, and take the mean of the three readings. Suppose 362 c.c. water were collected in *M*; gas burned 12 divisions, or 0.06 cu. ft.; difference in temperature of inlet and

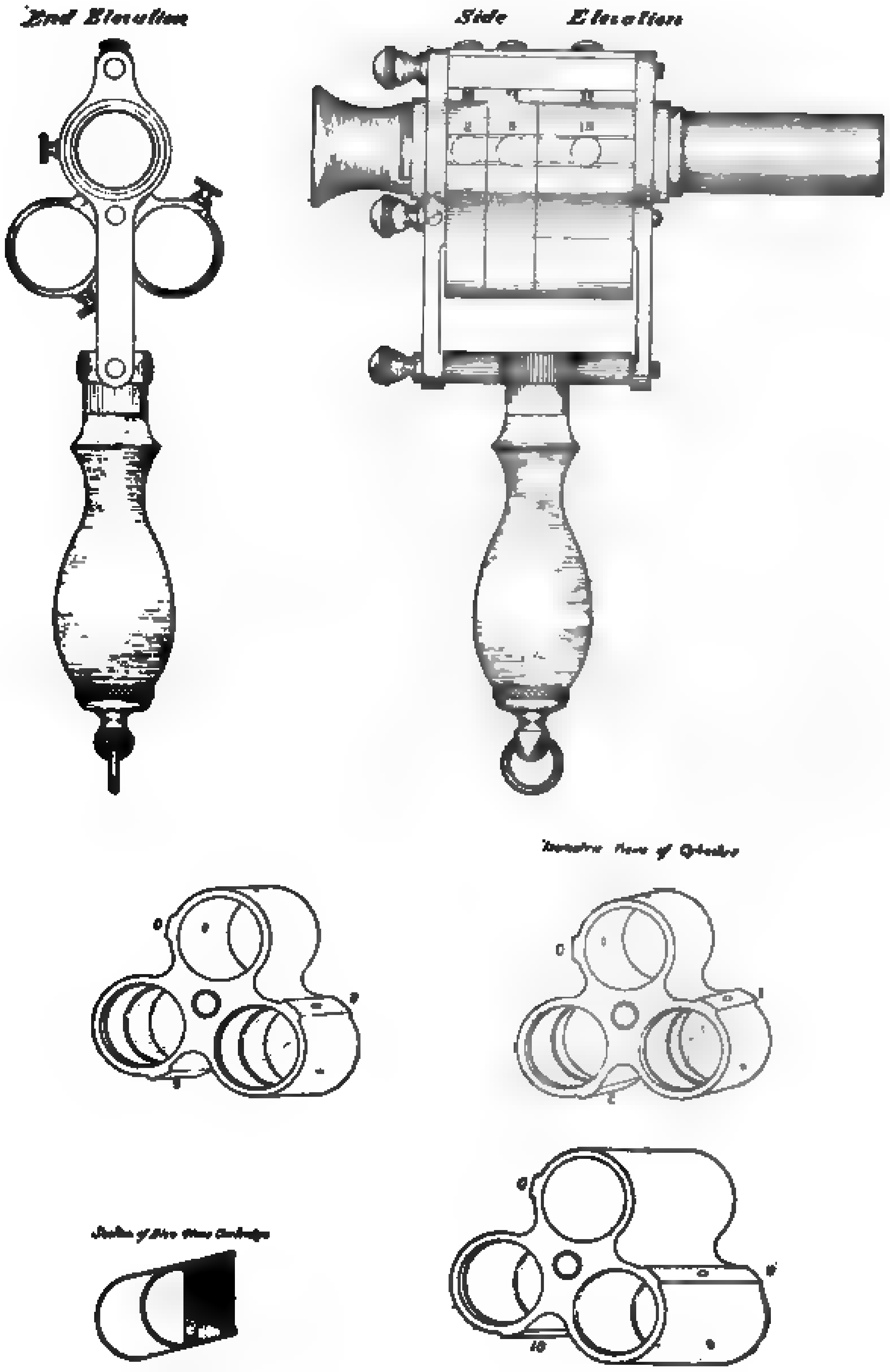


FIG. 82.—The Earnshaw Blue-glass Pyrometer.

exit water, $21.7-12.5=9.2$ deg. C. The makers supply a table in which 12 will be found at the head of a column, 362 in left-hand column, and 18.1 opposite, which being multiplied by 9.2 equals 166.52 calories per cu. ft.; or, $166.52 \times 3.97=661.08$ B.t.u. per cu. ft. of gas. The method thus simplified is not laborious. Suppose 3 c.c. of condensation water was collected, or 36 c.c. per cu. ft.; then $36 \times 0.6=21.6$ calories, which taken from 166.52 calories leaves 144.92 calories per cu. ft., net. Or, $36 \times 2.382 = 85.75$ B.t.u., which subtracted from 661.08 B.t.u. is 575.32 B.t.u., net. The same modifications can be made for testing oils as described under the Junker instrument. Another improved form has been devised by the Metropolitan Gas Referees of London, which aims still further to absorb the heat of combustion by the circulating water.

F. TEMPERATURES.

The Earnshaw Blue-glass Pyrometer, herewith illustrated in Fig. 82, is of the visual type, its principle being the absorption of light or its diminution, through the use of a varying number of slides or blue-glass lenses to create a vanishing point of light, said light of course presumed to vary directly as the intensity of the heat observed.

As the personal equation is very marked in the use of an instrument of this kind, its use would of course be of little service in establishing absolute values, but it will be found of extraordinary usefulness in making comparisons or establishing empiric tests.

Gas.—The theoretical flame temperature of a gas is the highest temperature that can be obtained by the combustion of the gas when no heat is lost in any way, all the heat that is developed being employed to heat up the products of combustion.

Hydrogen and hydrocarbon gases containing a large percentage of hydrogen yield upon combustion large weights of aqueous vapor, which has a high specific heat, and consequently, in spite of their high heating value, do not produce as high flame temperatures as do such gases as carbonic oxide, which have a lower heating value, but give smaller weights of products having a lower specific heat than aqueous vapor.

Since when the gas is burned in air the weight of the nitrogen mixed with the oxygen in the air is added to that of the products of combustion, the flame temperature is lower when the combustion takes place in air than it is for combustion in oxygen, as is practically illustrated in the oxyhydrogen flame.

The highest temperature that can theoretically be obtained by burning a gas in air is the temperature that will be reached when no heat is lost in any way, all the heat developed being employed to heat up the products of combustion and the nitrogen accompanying the oxygen drawn from the air for this combustion. These conditions are of course never obtained in practice, but, as it is very hard to measure accurately the losses that occur in practice, the maximum theoretical temperatures are used to furnish a basis for comparisons between different gases, it being assumed that the relations between the temperatures actually obtained will be nearly the same as those existing between the theoretical temperatures, although the absolute temperatures will be very different in the two cases.

This maximum theoretical temperature evidently depends upon the quantity of heat developed by the combustion of a unit weight of gas and upon the quantity of heat required to raise, by one degree, the temperature of the products resulting from the combustion of this unit weight, and the quotient obtained by dividing the quantity of heat produced by the quantity required to raise the temperature of the products of combustion one degree will give the highest temperature that can be reached by burning the given gas. The quantity of heat produced is given by the calorific value of the gas. The amount of heat required to raise the temperature of the products of combustion one degree can be calculated by multiplying the weight of each product that is produced by its specific heat, the nitrogen mixed with the oxygen in the air and drawn into the flame with it being included. It is therefore necessary to determine what substances are produced by the combustion of the gas and the weight of each of these substances that is obtained from the unit weight of the gases, to multiply the determined weight of each substance by its specific heat, and to add together the numbers obtained by these multiplications, the sum forming the divisor of the fraction.

The maximum temperature that can be produced by burning a gas in air can therefore be determined by dividing the calorific value of the gas per pound by the sum of the numbers obtained, by multiplying the weight of each of the products of combustion produced from one pound of gas by its proper specific heat, the nitrogen mixed in the air with the oxygen required for combustion being considered as one of the products of the combustion.

To illustrate by a simple example, the maximum temperature that can be produced by the combustion of carbonic oxide, CO, may be determined as follows:

1 lb. of CO requires for its combustion to carbonic acid, CO_2, 0.571 lb. of oxygen, which will have mixed with it in the air

$0.571 \times 3.31 = 1.89$ lbs. of nitrogen, N, and the products of the combustion of 1 lb. of CO will therefore be 1.571 lbs. of CO_2 and 1.89 lbs. of N. The calorific value of CO is 4383 B.t.u. per pound, the specific heats of CO_2 and N are respectively 0.217 and 0.244, and the equation of the maximum temperature in degrees Fahrenheit is

$$T = \frac{4383}{1.571 \times 0.217 + 1.89 \times 0.244} = \frac{4383}{0.802} = 5465° \text{ F.}$$

Melting-points.—For the determination of moderately high temperatures, such as that of hot blast supplied to furnaces, use is often made of metals or alloys of known melting-points, and when two such substances are procurable with melting-points differing only by a few degrees, the temperature of the blast, etc., can be readily kept within that range by regulating the heating apparatus, so that one test-piece is liquid and the other solid. By employing a series of test-pieces whose melting-points ascend by small and fairly regular increments a tolerably reliable measurement can be made of any temperature within the range of the test-pieces. Princeps alloys furnish us with fairly good means of reading temperatures between the melting-point of silver and that of platinum.

MELTING-POINTS OF PRINCEPS ALLOYS.

Percentage Composition of Alloy.			Melting-point, deg. C.	Percentage Composition of Alloy.			Melting-point, deg. C.
Silver.	Gold.	Platinum.		Silver.	Gold.	Platinum.	
100	..	..	954	..	60	40	1320
80	20	..	975	..	55	45	1350
60	40	..	995	..	50	50	1385
40	60	..	1020	..	45	55	1420
20	80	..	1045	..	40	60	1460
..	100	..	1075	..	35	65	1495
..	95	5	1100	..	30	70	1535
..	90	10	1130	..	25	75	1570
..	85	15	1160	..	20	80	1610
..	80	20	1190	..	15	85	1650
..	75	25	1220	..	10	90	1690
..	70	30	1255	..	5	95	1730
..	65	35	1285	..	..	100	1775

The values of the higher melting-points are probably within some twenty degrees of the truth.

TEMPERATURES OF MOLTEN IRON CORRESPONDING TO CERTAIN COLORS (POUILLET).

	Deg. Fah.
Intense white	2730
Bright white	2550
White heat	2370
Bright orange	2190
Orange	2010
Bright cherry	1830
Cherry-red	1650
Brilliant red	1470
Dull red	1290
Faint red	977

MELTING-POINT OF CAST IRON.

	Deg. Fah.
White	1920 to 2010
Gray	2010 to 2090

Optical Pyrometer.—The St. Jacques Lunette Pyrometrique is a polariscope arranged for plane polarized light, having between the analyzing and polarizing prisms a quartz crystal about 11 mm. long which has been cut perpendicular to its principal axis. The plane of polarization will be turned by such a piece of quartz through an angle that varies directly as the thickness of the quartz, and (approximately) inversely as the wave length of the light, so that the amount of rotation is much larger for the violet end of the spectrum than for the red. The higher the temperature the

INDICATIONS OF THE LUNETTE PYROMETRIQUE.

Character of Light.	Rotation Angle (Degrees).	Approximate Corresponding Temperature. C.	Approximate Corresponding Temperature. Fah.
Incipient cherry-red	33	800°	1470°
Cherry-red	40	900	1650
Light cherry-red	46	1000	1830
Slightly orange	52	1100	2010
Bright orange	57	1200	2190
White	62	1300	2370
Welding white	66	1400	2550
Brilliant white	69	1500	2730
Bright sunlight	84		

larger the proportion of light rays of short wave-lengths, consequently the larger the angle through which the analyzer must be rotated in order to obtain the "Extinction Tint"; this for low temperatures is a grayish yellow charged by a slight turning of the analyzer in either direction to green or red; for higher temperatures it is the same as for sunlight, a neutral purple changing to blue or red. For low temperatures where the light is feeble a condensing lens is employed to concentrate the beam for the polarizer. No useful indication can be obtained below incipient cherry-red. (See table at bottom of page 305.)

TEMPERATURES.

Degrees Fahrenheit $= \frac{9}{5}$ Degrees Centigrade $+32$, or F.° $= 1.8$ C.° $+32$.

Degrees Centigrade $= \frac{5}{9}$ (Degrees Fahrenheit -32).

Degrees Absolute Temperature, T. = C.° + 273.

" " " T. = F.° + 491.

Absolute Zero = $-273°$ on Centigrade Scale.

" " = $-491°$ on Fahrenheit Scale.

Mercury remains liquid to $-39°$ C., and thermometers with compressed N. above the column of mercury may be used for as high temperatures as 400° to 500° C.

HEAT-UNITS.

A French Calorie = 1 Kilogram of H_2O heated 1° C. at or near 4° C.

A British Thermal Unit (B.t.u.) = 1 lb. of H_2O heated 1° F. at or near 39° F.

A Pound-Calorie Unit = 1 lb. of H_2O heated 1° C. at or near 4° C.

1 French Calorie = 3.968 B.t.u. = 2.2046 Pound-Calories.

1 British Thermal Unit = .252 French Calories = .555 Pound-Calories.

1 Pound-Calorie = 1.8 B.t.u. = .45 French Calories.

1 B.t.u. = 778 ft.-lbs. = Joule's mechanical equivalent of heat.

1 H.P. = 33,000 ft.-lbs. per minute
$= \frac{33000}{778} = 42.42$ B.t.u. per minute
$= 42.42 \times 60 = 2545$ B.t.u. per hour.

The British Board of Trade unit is not a unit of heat, but of electrical measurement and

= 1 kilowatt hour
= 1000 watts $= \frac{1000}{746} = 1.34$ H.P. per hour.

TEMPERATURES IN SOME INDUSTRIAL OPERATIONS.

	Centigrade Degrees.	Fahrenheit Degrees.
Gold—Standard alloy, pouring into molds	1180	2156
Annealing blanks for coinage, furnace chamber	890	1634
Silver—Standard alloy, pouring into molds	980	1796
Steel—Bessemer Process, Six-ton Converter:		
Bath of Slag	1580	2876
Metal in ladle	1640	2984
" " ingot mold	1580	2876
Ingot in reheating furnace	1200	2192
" under hammer	1080	1976
Siemens Open-hearth Furnace:		
Producer-gas near gas-generator	720	1328
" entering recuperator chamber	400	752
" leaving " "	1200	2192
Air issuing from " "	1000	1832
Products of combustion approaching chimney	300	590
End of melting pig charge	1420	2588
Completion of conversion	1500	2732
Pouring steel into ladle, beginning	1580	2876
Pouring steel into ladle, ending	1490	2714
In the molds	1520	2768
Siemens Crucible Furnace:		
Temperature of hearth between crucibles	1600	2912
Blast-furnace on Gray Bessemer:		
Opening in front of tuyère	1930	3506
Molten metal, beginning to tap	1400	2552
Molten metal, end of tap	1570	2858
Siemens Glass-melting Furnace:		
Temperature of furnace	1400	2552
Melted glass	1310	2390
Annealing bottles	585	1085
Furnace for hard porcelain, end of "baking"	1370	2498
Hoffman red-brick kiln, burning temperature	1100	2012

MELTING-POINTS.

	C.°	F.°		C.°	F.°
Sulphur	115	239	Copper	1054	1929
Tin	230	446	Cast iron, white	1135	2075
Lead	326	618	" " gray	1220	2228
Zinc	415	779	Steel, hard	1410	2570
Aluminium	625	1157	" mild	1475	2687
Silver	945	1733	Palladium	1500	2732
Gold	1045	1913	Platinum	1775	3227

MELTING-POINTS (ANOTHER AUTHORITY).

Substance.	Degrees Fah.	Substance.	Degrees Fah.
Aluminium	1247	Phosphorus	111
Antimony	797	Platinum	3227
Bismuth	505	Potassium	136
Bronze	1652	Silver	1832
Butter	91	Sodium	203 to 204
Copper	2102	Spermaceti	120
Gold	2192	Stearine	131
" coined	2156	Steel	2372 to 2552
Ice	32	Sulphur	230
Iodine	237	Tin	540
Iron, cast	1922 to 2382	Wax, white	154
" wrought	2732 to 2912	Wax, yellow	144
Lead	617	Zinc	786

G. HEAT DATA.

Heat Radiation.—Good heat radiators are good absorbers to an equal degree, and reflecting power is the exact inverse of radiating power.

RELATIVE VALUE OF RADIATORS.

Substance.	Relative Radiating Value.
Lampblack or soot	100
Cast iron, polished	26
Wrought iron, polished	23
Steel, polished	18
Brass, polished	7
Copper, polished	5
Silver, polished	3

Conduction is the transfer of heat by contact, molecular motion being then directly caused. Heat is thus transmitted through the thickness of a furnace-tube. There are good and bad conductors, the former being chosen for fire-boxes, other properties being suitable.

RELATIVE VALUE OF GOOD HEAT CONDUCTORS.

Substance.	Relative Conducting Value.
Silver	100
Copper	73.6
Brass	23.1
Iron	1.91
Steel	11.6
Platinum	8.4
Bismuth	1.8
Water	0.147

Bad conductors are of value for covering boilers, steam-cylinders, pipes, etc.

RELATIVE VALUE OF HEAT INSULATORS.

Substance.	Relative Insulating Value.
Silicate cotton or slag wool	100
Hair felt	85.4
Cotton wool	82
Sheep's wool	73.5
Infusorial earth	73.5
Charcoal	71.4
Sawdust	61.3
Gas-works breeze	43.4
Wood, and air-space	35.7

EXPANSION OF LIQUIDS IN VOLUME.

Volume at 32 deg. Fah. = 1.	Volume at 212 deg. Fah.
Water	1.046
Oil	1.080
Mercury	1.018
Spirits of wine	1.110
Air	1.373 to 1.375

LINEAL EXPANSION OF METALS PRODUCED BY RAISING THEIR TEMPERATURE FROM 32° TO 212° FAH.

Zinc	1 part in 322	Gold	1 part in 682
Lead	" " " 351	Bismuth	" " " 719
Tin (pure)	" " " 403	Iron	" " " 812
Tin (impure)	" " " 500	Antimony	" " " 923
Silver	" " " 524	Palladium	" " " 1000
Copper	" " " 581	Platinum	" " " 1100
Brass	" " " 584	Flint glass	" " " 1248

COEFFICIENTS OF LINEAR EXPANSION.

	Elongation per deg. C.
Glass	0.0000085
Platinum	.0000085
Cast iron	.00001
Wrought iron	.000012
Copper	.000017
Lead	.000028
Zinc	.00003
Brass	.000019

RELATIVE POWER OF METALS FOR CONDUCTING HEAT.

Gold	1000	Iron	374.3
Silver	973	Zinc	363
Copper	898.2	Tin	303.9
Platinum	381	Lead	179.6

Excess of Temperature in the Gas in the Pipes over that of the Atmosphere. For an Excess of	Quantity of Heat Lost by a Square Unit of Exterior Pipe Surface	
	When Radiating in Air.	When Plunged in Water.
10°	8	88
20°	18	266
30°	29	5,353
40°	40	8,944
50°	53	13,437

COMPARATIVE POWER OF SUBSTANCES FOR REFLECTING RADIANT HEAT.

Polished brass	100
Silver	90
Tin	80
Steel	60
Lead	60
Glass	10
Lampblack	0

RELATIVE POWER OF METALS FOR REFLECTING HEAT.

Intensity of direct radiation = 1.00.

Silver plate	0.97	Polished platinum	0.80
Gold	0.95	Steel	0.83
Brass	0.93	Zinc	0.81
Speculum metal	0.86	Iron	0.77
Tin	0.85		

CHAPTER XX.

STEAM.

A. PROPERTIES OF STEAM.

THE conversion of water into steam is attended with certain heat phenomena which may be developed as follows:

Latent Heat.—The term latent heat is applied to the heat added to or abstracted from a substance to change its state without changing its temperature. Thus 144 B.t.u. must be added to 1 pound of ice to convert it into water at 32 deg. F. This can be found by direct experiment by allowing ice to melt in water, the heat lost by the water being absorbed by the ice. Suppose 2 oz. (w_1) of ice at 32 deg. F. are added to 20 oz. of water (w) at 60 deg. F. (t_1) which was at 45 deg. F. when the ice was melted, 1 deg. being obtained from the higher temperature of the room, making the corrected final temperature (t_2) 44 deg. F. Then

Heat lost by the water = heat gained by the ice.

$$w(t_2 - t_1) = w_1[L + (t_2 - 32)],$$
$$20(60 - 44) = 2[L + (44 - 32)],$$
$$\text{Latent heat, } L = (320 - 24) \div 2 = 148.$$

The exact value is more nearly 144 B.t.u. The calorimeter shown in Fig. 83 is often used for such experiments. A metal vessel B contains in its air-space another vessel surrounded by non-conducting material like felt and is provided with a thermometer for taking the temperature of the water. The Siemens pyrometer resembles this apparatus, the copper cylinder being brought up to the temperature of the furnace to be tested and then quickly thrown into the known weight of water; when the temperature becomes constant after gently stirring the heat lost by the copper will equal the heat gained by the water, as before, but the calculation is as follows:

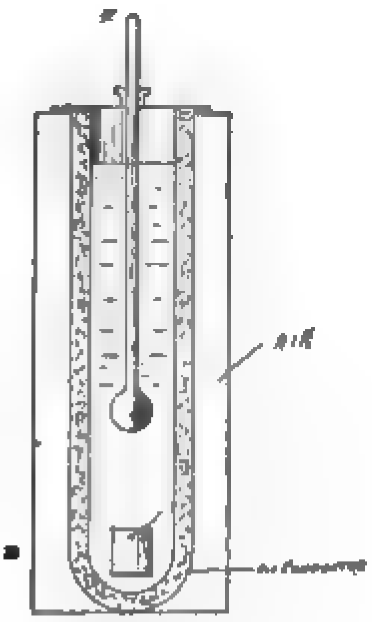


FIG. 83.—Calorimeter.

Weight × specific heat × decreased temperature of copper
= weight × increased temperature of the water.

$$w_1 \times 0.95(T-t_2)=w(t_2-t_1),$$

where T is the temperature of the furnace and the other terms have the same values as before.

When water is heated the rise in temperature ceases at 212 deg. F. (100 deg. C.) until all the water has been converted into steam without raising the pressure. The heat continually added goes to change the condition of water from that of a liquid to a vapor. This heat may be determined by the apparatus shown in Fig. 84.

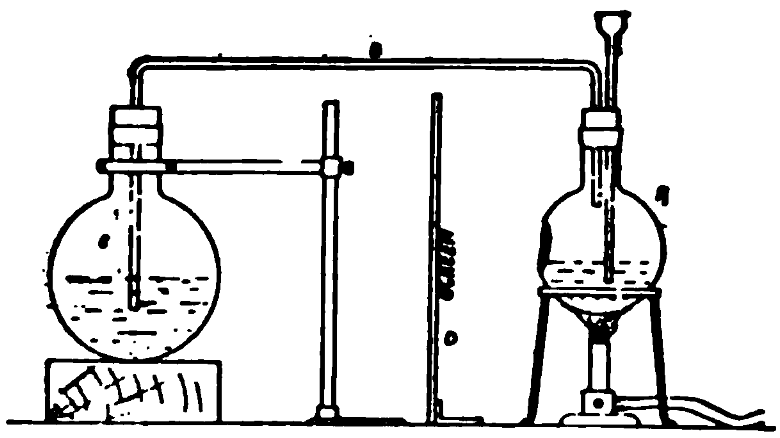


FIG. 84.—Apparatus for Testing Latent Heat of Steam.

Water is boiled in flask A, steam passing from A through B to flask C into water, which condenses it. This continues until the water in C nearly boils. The difference in weight of C before and after the test will give the weight of steam condensed (w). Since the heat lost by the steam equals that gained by the water,

$$w(212+L-t_2)=w_1(t_2-t_1),$$

or if there was 20 oz. of water in C at 70 deg. F. and the steam condensed was 1.5 oz., increasing the temperature to 147 deg.,

$$1.5(212+L_h-147)=20(147-70),$$
$$L_h=(1540-97.5)\div 1.5=931.6 \text{ B.t.u.}$$

The exact value for the latent heat of steam is 966 B.t.u.

It should be well grasped that latent heat is a kind of specific heat given to the body during the change from solid to liquid and from liquid to gaseous. In the reverse order an equal quantity of heat is given out. Thus 1 lb. of ice below 32° will give out or absorb 0.5 unit for every degree, and 144 units when melting. Water between 32° and 212° will require 1 unit per lb. Finally, if the steam be superheated beyond 212°, 0.48 unit will raise each pound by one degree at a time.

Fig. 85 shows the changes indicated, *ABC* being the curve of volumes, with *DEF* as base, and the dotted line a curve of corre-

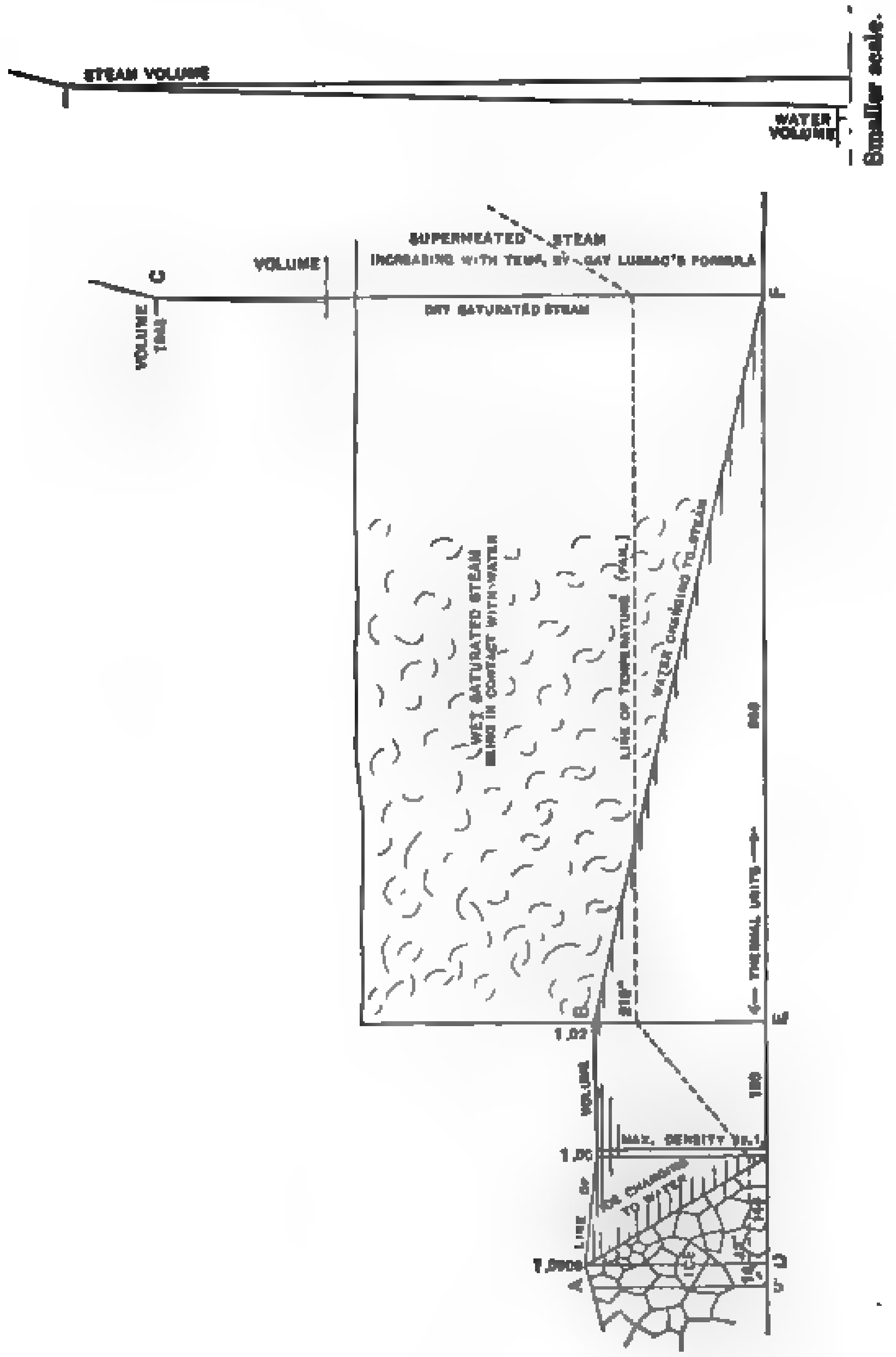


FIG. 85.—Relative Volumes and Temperatures of Ice, Water, and Steam, and Heat Supplied.

sponding temperatures. The base-line lengths indicate units of heat required to change both volume and temperature under atmos-

pheric pressure. The steam volume at F is too great to be shown on the diagram, but is given to a smaller scale at G and to a still smaller scale at C. The base of these narrow triangles corresponds to EF.

Water will boil at 212° F. under 14.7 lbs. per sq. in. pressure, but if the pressure is decreased the boiling-point is lowered, and if the pressure increases the boiling-point will be above 212 deg. When steam is in contact with boiling water it is wet or saturated, but when all water has been evaporated it becomes dry steam; further addition of heat forms superheated steam, which behaves like a fixed gas in that condition. In Fig. 85 the volume of steam is 1650 times that of the water from which it was formed, while 1 lb. of water will form 26.36 cu. ft. of steam.

The relation of temperature to pressure for the range of −32 to 32 deg. F. was tested by Gay-Lussac in the apparatus shown in

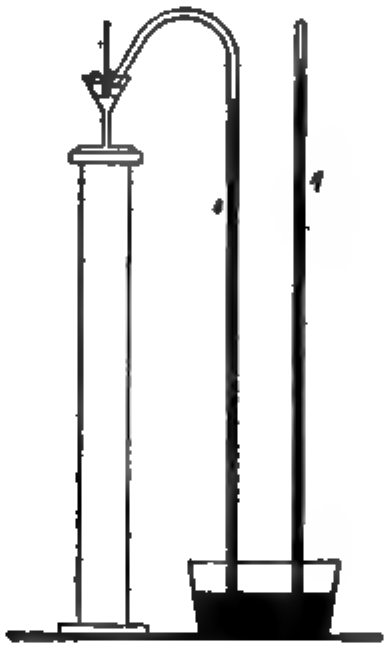


FIG. 86.

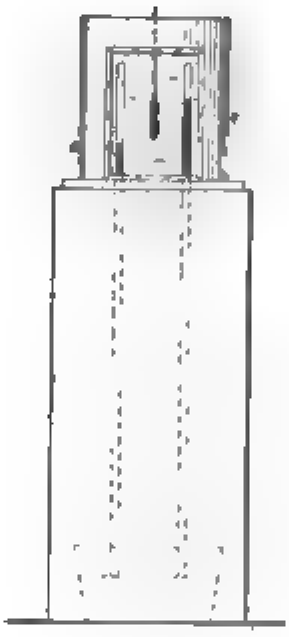


FIG. 87.

FIG. 86.—Tension of Aqueous Vapor at Low Temperatures.
FIG. 87.—Tension of Aqueous Vapor at Medium Range.

Fig. 86, consisting of two barometer tubes in mercury, tube B containing some water above the mercury in its end, the temperature of which was regulated by freezing-mixtures as shown.

For the temperature ranges from 32 deg. to 122 deg. Regnault used the apparatus shown in Fig. 87, in which tube B again has a little water on the surface of the mercury. The ends of the barometer tubes are surrounded by water which is readily brought to the temperature desired.

The tension of aqueous vapor and steam between the temperatures of 122 deg. and 219 deg. F. (since it has been carried to 432

deg.) was found by Regnault in the apparatus shown in Fig. 88, where A is a boiler in which steam is formed which is condensed by the water-jacket circulating water from D to E, B is a copper sphere in which the pressure is regulated by the pump C and measured by the U gage F. The thermometers in A measure the temperature of the steam, and the very high tube G permitted of pressures up to 24 atmospheres.

The relation between temperature and specific volume or cubic feet per pound was determined by Fairbairn and Tate in the apparatus shown in Fig. 89, where a glass sphere A dips its open stem into mercury in tube E connected with B, containing water. A known weight of water is placed in A while D and B are heated. As the tension in A and B are equal at first the mercury columns are at the same level, but when the water in A has evaporated,

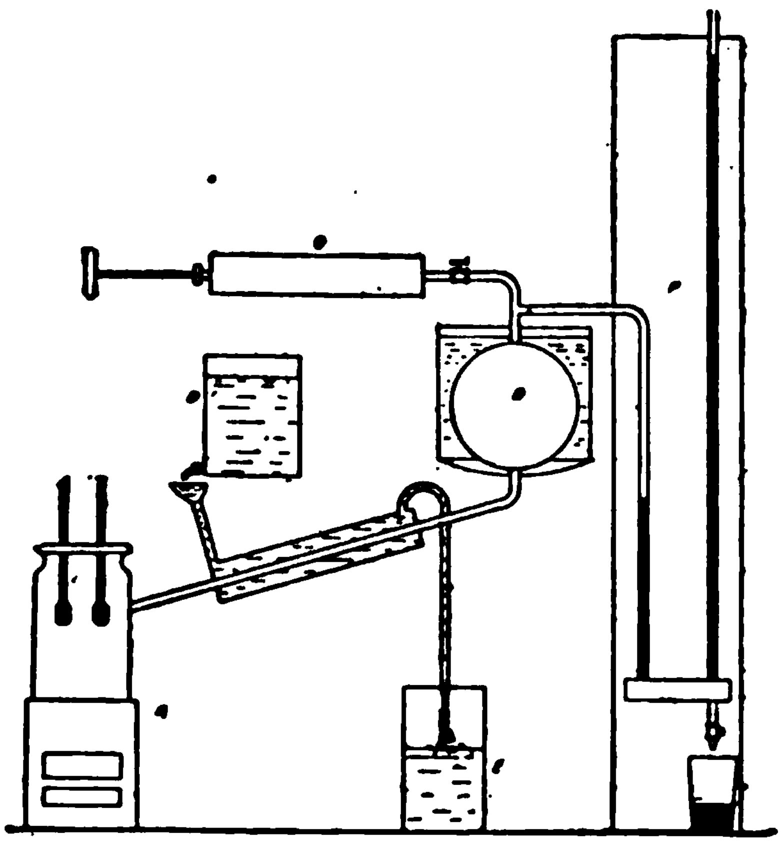


FIG. 88.—Vapor Tension of Steam.

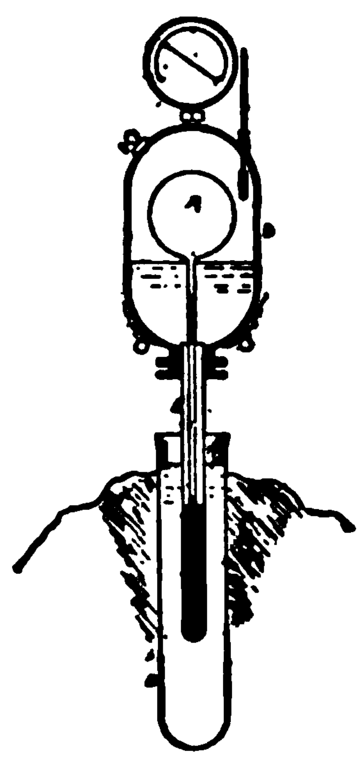


FIG. 89.—Testing for Specific Volume.

the vapor begins to superheat and the pressure becomes less than in B, which is still evaporating, so that the mercury-column levels separate. At this moment the steam in A is dry, its volume is known, and its weight, from which its specific volume at that temperature is readily found. The results from these experiments are shown by the curves of Fig. 90, where the curve to the left shows the rise in temperature and the curve to the right the decrease in specific volume as the absolute pressure (atmospheric + pressure above atmospheric) increases.

The total heat of evaporation is the quantity of heat required to raise the temperature of water from freezing-point to boiling-point and just convert it into steam. Regnault investigated the

total heat of steam in an apparatus shown in Fig. 91, consisting in a steam-boiler from which steam was taken through *c* into a coil, *A*, immersed in water connected with a bulb, *B*, in which the pressure could be regulated by the pump shown, and measured by the mercury column as shown in Fig. 88. Thermometers showed the temperatures of steam and cooling-water. From his experiments Regnault found that the total heat was equal to $1092+0.3\ (t^{\circ}-32^{\circ})$. By deducting the sensible heat, $t^{\circ}-32^{\circ}$, the latent heat remained

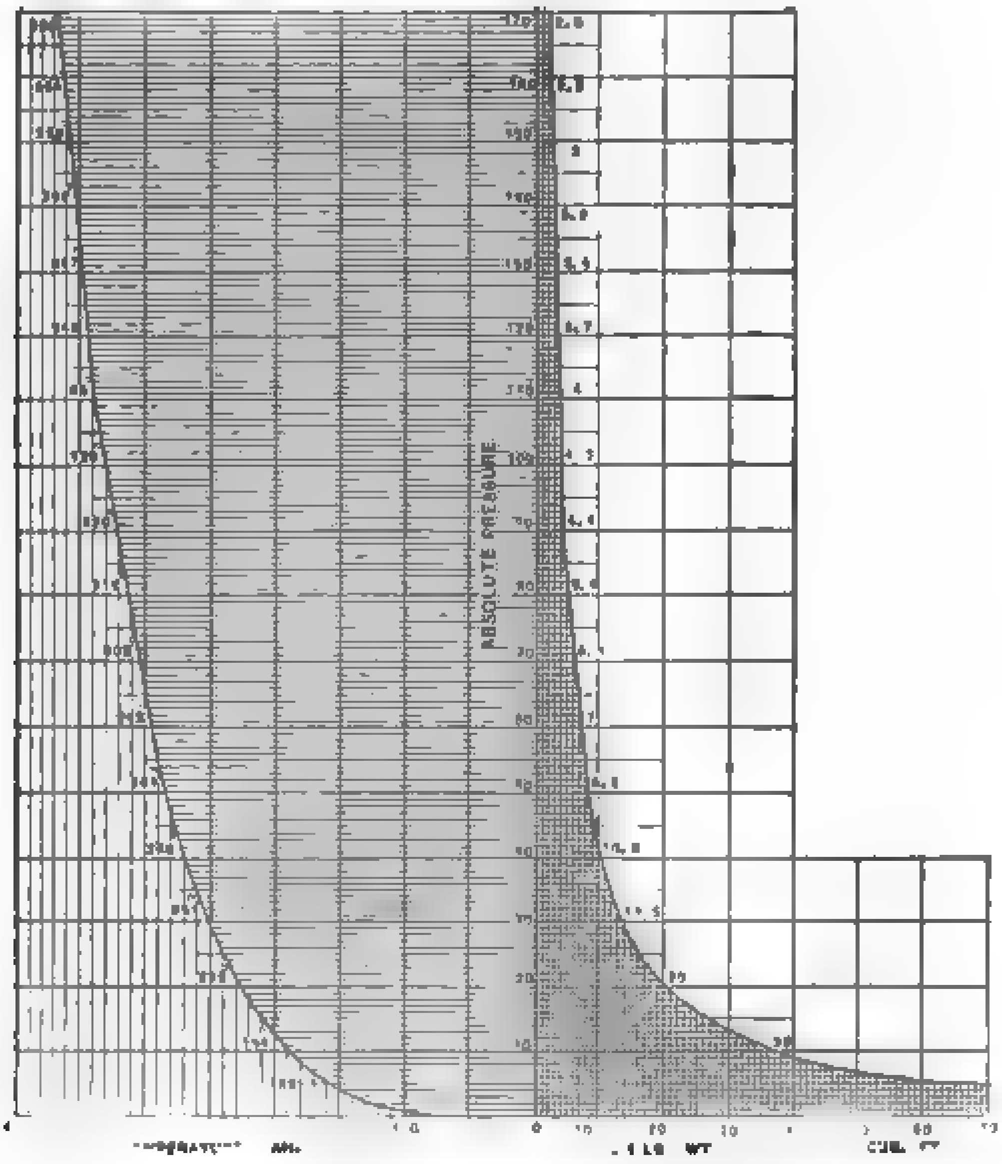


FIG. 90.—Relation of Pressure, Temperature, and Volume of Saturated Steam.

as $1092-0.7\ (t^{\circ}-32^{\circ})$. To find a formula applicable to any temperature for saturated steam above or below 212 deg. this formula becomes

$$L=966-0.7(t^{\circ}-212^{\circ})=1115-0.7\,t^{\circ}.$$

In condensing steam the heat lost by the steam equals the heat gained by the water. Suppose the temperature of exhaust-steam

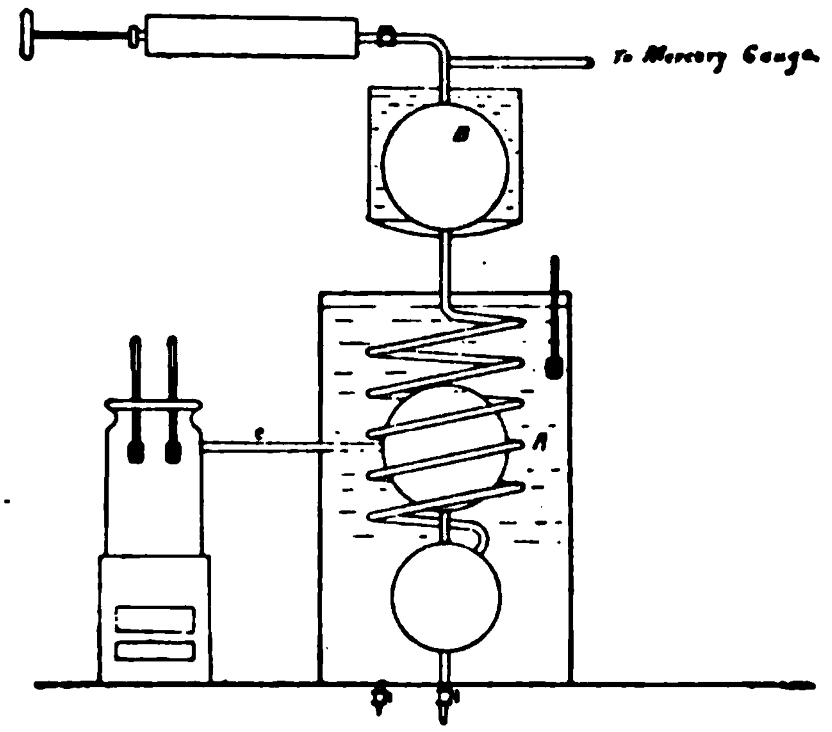


Fig. 91.—Testing for Total Heat in Steam.

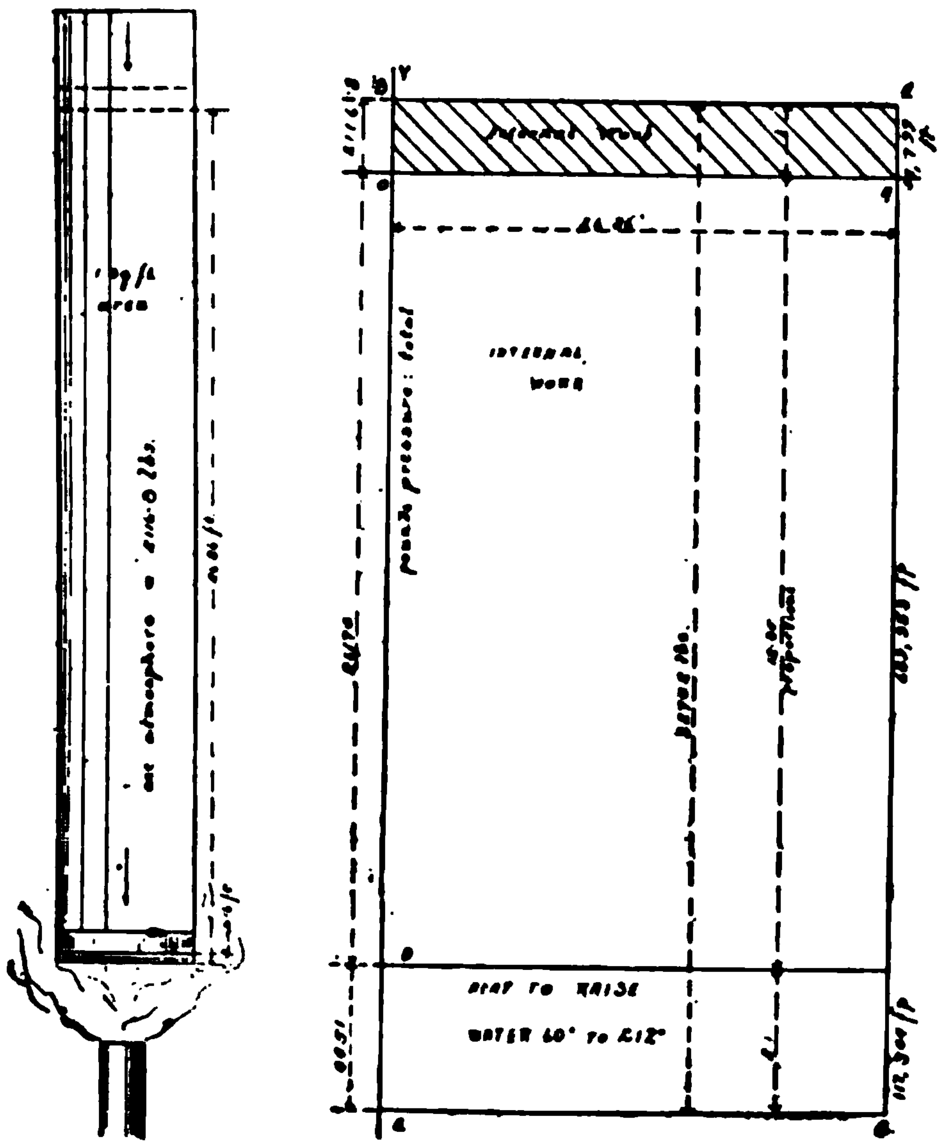


Fig. 92.—Graphical Diagram showing Distribution of Work.

to be 193 deg. F., that of the condensing water on entering 60 deg. and at exit 120 deg., then

$$966-0.7(212-193)+(193-120)=w_1(120-60),$$
$$w_1=17.53 \text{ lbs.}$$

Work in Steam.—When steam is formed it occupies a relatively much greater volume than the water from which it had been formed; this expansion could take place only against the resistance of material previously occupying that space, and work is therefore done. This is illustrated in Fig. 92, where one pound of water is supposed to be heated in the tube having a piston above it of 1 square foot area. The steam pushes it upward against one atmosphere, or 14.7 lbs. per sq. in., or $14.7 \times 144 = 2116.8$ lbs. As 1 cu. ft. of water weighs 62.5 lbs. it will stand $1 \div 62.5 = 0.016$ foot high in the tube. The specific volume of 1 lb. of steam at 212 deg. is 26.36 cu. ft., attained by doing $2116.8 \times 26.36 = 55{,}799$ ft.-lbs. of work. The latent heat of steam absorbed $966 \times 772 = 745{,}752$ ft.-lbs. Taking from this 55,799 leaves 689,935 ft.-lbs. for internal work. Raising the temperature of water from 60 deg. to 212 deg. required $152 \times 772 = 117{,}344$ ft.-lbs. This may be summed up as

$$\text{Total work} = [966 + 180° - (60° - 32°)]772 = 863{,}096 \text{ ft.-lbs.}$$

Thus 2.1 parts of the work went to raise the temperature of the water 12.36 to internal work of changing water into steam and 1 part to external work of raising the piston or expansion. In the diagram let *OA* be 26.36 and *OB* 2116.8 lbs.; then the shaded rectangle will represent external work. Make *OD* and *DE* 12.36 and 2.1 times *OB* respectively; the rectangle *OD* and *DG* will represent internal work and sensible heat respectively. The shaded area represents only useful work. The efficiency of steam-formation work therefore is $55{,}799 \div 863{,}096 = 0.0646$. Using these figures, let us take the example of a triple-expansion engine operating with steam at 160 lbs. gage pressure, or $160 + 14.7 = 174.7$ lbs. absolute pressure. Thence we have

Specific volume of steam, cu. ft.	2.5
Load on piston, 144×174.7 lbs.	25,156.0
External work, $2.5 \times 25{,}156$ lbs.	62,890.0
Temperature of steam, deg. F.	370.0
Latent heat, $[966 - 0.7(370 - 212)] \times 772$ ft.-lbs.	660,369.0
Internal work, $660{,}369 - 62{,}890$ ft.-lbs.	597,479.0
Raising temperature of water, $(370 - 60)772$ ft.-lbs.	239,320.0
Total work, $62{,}890 + 597{,}479 + 239{,}320$ ft.-lbs.	899,689.0

$$\text{Efficiency of steam} = \frac{\text{external work}}{\text{total work}} = \frac{62{,}890}{899{,}189} = 0.07,$$

which shows that high-pressure steam is not more economical than low-pressure steam, weight for weight.

Specific Heat.—The relative quantity of heat required to raise the temperature of a substance 1 deg. F., as compared with water,

is termed its specific heat. As applied to gases it refers to two conditions—constant volume and constant pressure, the temperature varying in both cases. As 1 cu. ft. of air weighs 0.0803 lb., 1 lb. will occupy 12.4 cu. ft. at 1 atmosphere pressure and 32 deg. F. If it is heated to 212 deg. F., a rise of 180 deg. F., the increase in volume will be $(180 \div 492)12.4 = 4.54$ cu. ft., which represents the rise of the piston in Fig. 92 against 2116.8 lbs. The external work will therefore be $2116.8 \times 12.4 = 9510.27$ ft.-lbs. The specific heat of gases at constant pressure is 0.2375; thus the heat absorbed in raising the temperature of the air 180 deg. will be $180 \times 0.2375 = 42.75$ B.t.u. $= 33{,}003$ ft.-lbs. The difference, which is internal work, will therefore be $33{,}003 - 9510.27 = 23{,}492.75$ ft.-lbs. $=$ 30.43 B.t.u. Therefore the specific heat, constant volume, $= 30.43 \div 180 = 0.1672$ B.t.u., or, more correctly, 0.1686 B.t.u. The ratio of specific heats will therefore be $0.2375 \div 0.1686 = 1.408 = y$. When specific heats are represented in foot-pounds the symbols K_p and K_v may be used.

According to Regnault's law the specific heat of a gas at constant pressure is the same at all temperatures. Suppose a gas to be heated under the constant pressure P, its volume being increased from V_1 to V_2 and the absolute temperature rising from T_1 to T_2, then the

$$\begin{array}{lll} \text{External work} & = P(V_2 - V_1) = c(T_2 - T_1), \\ \text{Total} \quad `` & = K_p(T_2 - T_1), \\ \text{Internal} \quad `` & = K_p(T_2 - T_1 - c(T_2 - T_1). \end{array}$$

Since only internal work is done when gas is heated at constant volume,

$$K_v(T_2 - T_1) = K_p(T_2 - T_1 - c(T_2 - T_1),$$
$$C = K_p - K_v.$$

Note that the internal work $K_v(T_2 - T_1)$ may be either positive, negative, or nothing.

Superheated Steam.—By experiment $K_p = 370.56$ ft.-lbs. Steam behaves like a perfect gas a few degrees above its saturation point, K_p being practically a regular quantity. The ratio of the specific volumes of air to superheated steam is 0.622, and the constant C for steam equals the constant C for air divided by 0.622 or 85.5. Therefore

$$C = K_p - K_v = 85.5, \qquad K_v = 370.56 - 85.5 = 285.06 \text{ ft.-lbs.},$$

$$y = \frac{K_p}{K_v} = \frac{370.56}{285.06} = 1.3.$$

Expansion Curves.—The hyperbola illustrating Boyle's law is shown in Fig. 93, and expresses the relation

$$PV=C.$$

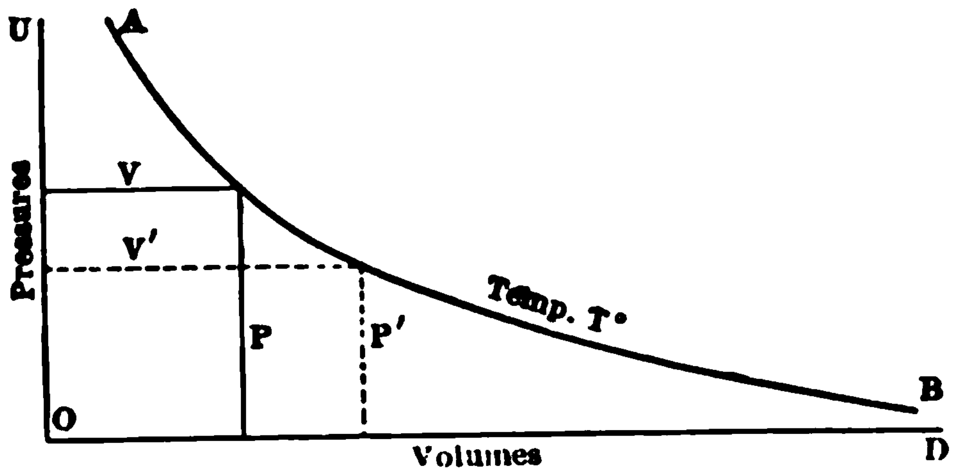


FIG. 93.—Hyperbolic Expansion Curve.

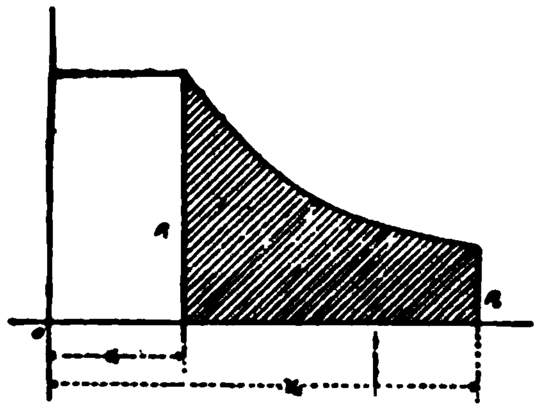


FIG. 94.—Expansion Area.

Another expansion curve has the formula $PV^n=C$, the exponent n changing with the material. The shaded area shows the work done during expansion, Fig. 94, and could be measured, but since the curve has a definite formula its area may be found by the formula

$$\text{Area}=PV\log_e\frac{V_2}{V_1}.$$

This of course requires the use of a table of hyperbolic logarithms. The area of the curve having the formula $PV^n=C$ is

$$\text{Area}=\frac{P_1V_1-P_2V_2}{n-1}.$$

An isothermal curve follows the law of Boyle, the heat transformed into work during expansion being supplied so that the

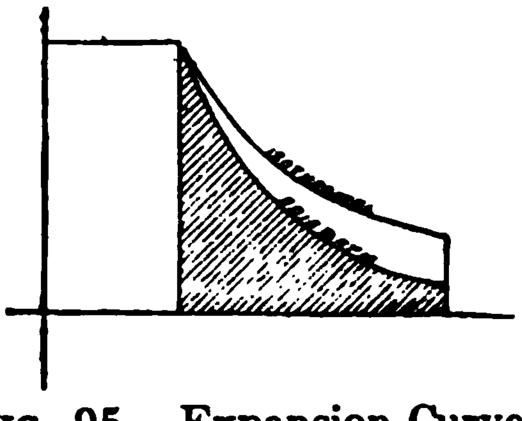


FIG. 95.—Expansion Curves.

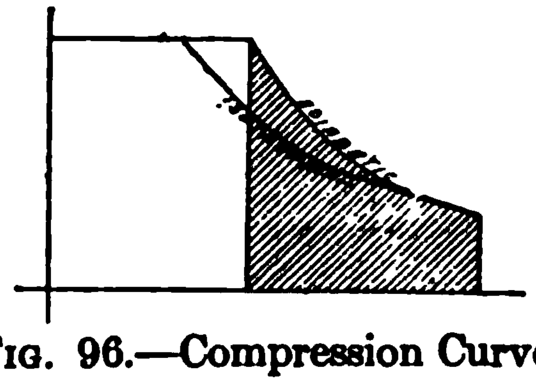


FIG. 96.—Compression Curves.

temperature remains constant. If no heat is supplied, the curve will fall below the hyperbola as shown in Fig. 95. In compression

the curve would rise above the isothermal as the gas becomes heated by work done upon it, as shown in Fig. 96.

The value of the exponent n for the adiabatic expansion curve is thus developed:

$$\text{Area of curve} = \frac{P_1V_1 - P_2V_2}{n-1} = \frac{c}{n-1}(T_2 - T_1) = \text{external work.}$$

$$\begin{aligned} \text{Total work} &= \text{internal work} + \text{external work} \\ &= K_v(T_2 - T_1) + \frac{c}{n-1}(T_2 - T_1) \\ &= \left(K_v + \frac{c}{n-1}\right)(T_2 - T_1) \\ &= \left(\frac{nK_v - K_p}{n-1}\right)(T_2 - T_1). \end{aligned}$$

Since no heat is added nor abstracted in adiabatic expansion this last expression is equal to zero; since the factor $(T_2 - T_1)$ is tangible,

$$nK_v - K_p = 0 \quad \text{and} \quad n = \frac{K_p}{K_v} = y,$$

and

$$PV^y = C$$

is the general equation for adiabatic expansion. External work is done at the expense of the heat in the gas. Therefore, in adiabatic expansion

$$P_2V_2{}^y = P_1V_1{}^y, \qquad P_2V_2V_2{}^{y-1} = P_1V_1V_1{}^{y-1},$$

$$P_2V_2 = P_1V_1\left(\frac{V_1}{V_2}\right)^{y-1} = cT_2 = cT_1\left(\frac{V_1}{V_2}\right)^{y-1},$$

$$T_2 = T_1\left(\frac{T_1}{T_2}\right)^{y-1}, \quad \text{or} \quad T_2 = T_1\left(\frac{T_1}{T_2}\right)^{0.408} \text{ for air.}$$

The formula thus far developed may now be collected:

Isothermal expansion, $PV = C$.

Adiabatic " $PV^{\gamma} = C$ $\begin{cases} \gamma = 1.408 \text{ for air} \\ \quad = 1.3 \text{ for sup. steam,} \end{cases}$

Saturated steam expansion, $PV^{\frac{17}{16}} = C$ (Rankine; $= .475$,

Adiabatic " " $PV^{1.135} = C$ (Zeuner),

" " " $PV^{\frac{10}{9}} = C$ (Rankine),

" superheated steam expansion, $PV^{1.3} = C$.

These adiabatic curves represent the expansion of steam in a cylinder under good conditions. As shown in Fig. 97, all start-

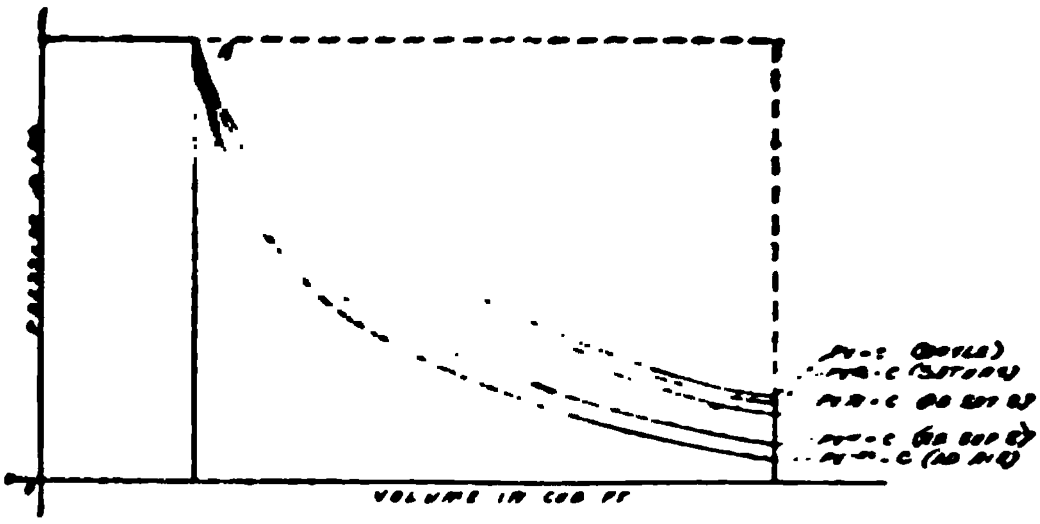


FIG. 97.—Curves Compared.

ing at the same point, the hyperbolic curve lies highest and the adiabatic for air lowest.

By consulting Fig. 98 it will be seen that AB is the curve for dry steam; if V is decreased by compression at constant tempera-

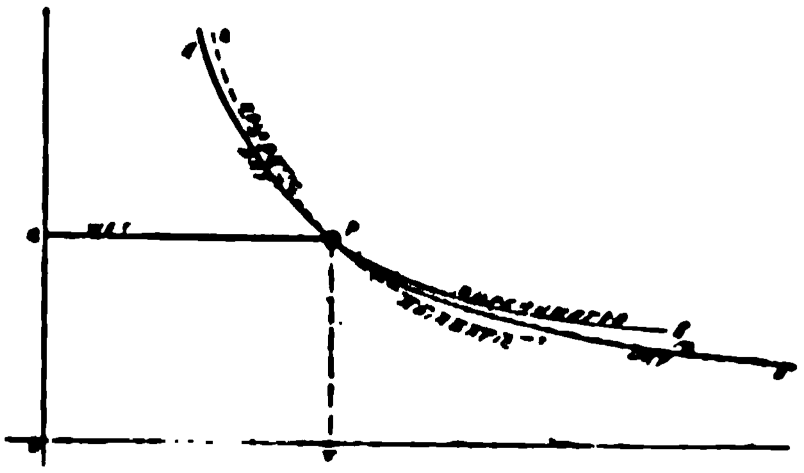


FIG. 98.—Curves of Wet and Dry Steam.

ture the steam becomes wet, but if V is increased the steam becomes superheated and has the formula $PV^{1.135} = C$. Tables I and II give the properties of dry saturated steam and facts connected with steam generation.

Table II gives the properties of dry saturated steam for differences of 1 lb. per sq. in. pressure and ranges usual in steam-boiler practice.

I. PROPERTIES OF SATURATED STEAM.

Absolute Pressure.	Gage Pressure.	Temperature F.	Weight in Pounds per Cubic Foot of Steam.	Volume in Cubic Feet of One Pound of Steam.	Total Heat above 32° F.		Latent Heat, Heat-units.
					In the Water, Heat-units.	In the Steam, Heat-units.	
1	−27.9	102.1	.003	334.23	70.09	1113.1	1043.0
5	−19.7	162.3	.014	72.50	130.7	1131.4	1000.7
10	− 9.6	193.2	.026	37.80	161.9	1140.9	979.0
14.7	0.	212.0	.038	26.36	180.9	1146.6	965.7
15	.3	213 0	.039	25.87	181.9	1146.9	965.0
20	5.3	227.9	.050	19.72	197.0	1151.5	954.4
25	10.3	240.0	.063	15.99	209.3	1155.1	945.8
30	15.3	250 2	.074	13 48	219.7	1158.3	938.9
35	20.3	259.2	.086	11.66	228.8	1161.0	932.2
40	25.3	267.1	.097	10.28	236.9	1163.4	926.5
45	30.3	274.3	.109	9.21	244.3	1165.6	921.3
50	35.3	280.9	.120	8 34	251 0	1167.6	916.6
55	40.3	286.9	.131	7.63	257.2	1169 4	912 3
60	45.3	292 5	.142	7 03	262.9	1171 2	908.2
65	50.3	297.8	.153	6.53	268.3	1172 8	904.5
70	55.3	302.7	.164	6.09	273.4	1174.3	900.9
75	60.3	307.4	.175	5.71	278.2	1175 7	897.5
80	65 3	311.8	.186	5.37	282.7	1177.0	894.3
85	70 3	316.0	.197	5.07	287.0	1178 3	891.3
90	75.3	320.0	[illegible]	4.81	291.2	1179.6	888.4
95	80.3	323.9	.219	4.57	295.1	1180.7	885.6
100	85.3	327.6	.230	4.36	298.9	1181.8	882.9
110	95.3	334.5	.251	3 98	306.1	1184.0	877.9
120	105.3	341.0	.272	3.67	312.8	1185.9	873.2
130	115 3	347.1	.294	3 41	319.1	1187.8	866.7
140	125 3	352 8	.315	3.18	325.0	1189.5	864 6
150	135.3	358.2	[illegible]	2.98	330.6	1191.2	[illegible]
160	145 3	363 3	.357	2.80	335.9	1192.7	856.9
170	155.3	368 2	.378	2.65	340 9	1194 2	853.3
180	165.3	372.8	[illegible]	2.51	345 8	1195.7	849.9
190	175.3	377.3	.419	2.39	350.4	1197.0	846.6
200	185.3	381.6	.440	2.27	354 9	1198 3	843.4
210	195.3	385 7	.461	2.17	359.2	1199 6	840.4
220	205.3	389.7	.485	2 06	362.2	1200.8	838.6
230	215 3	393.6	.506	1.98	366.2	1202.0	835.8
240	225 3	397 3	.527	1.90	370.0	1203.1	833.1
250	235 3	400 9	.548	1.83	373.8	1204.2	830.5
300	285.3	417.4	.651	1.535	390.9	1209.2	818 3
400	385.3	444.9	.857	1.167	419.8	1217.7	797.9
500	485.3	467.4	1.062	.942	443.5	1224.5	781.0
600	585.3	486.9	1.266	.790	464.2	1230.5	766 3
700	685.3	504.1	1.470	.680	482.4	1235.7	753 3
800	785 3	519.6	1.674	.597	498.9	1240.3	741.4
900	885.3	533.7	1.878	.532	514.0	1244.7	730.6
950	935.3	540.3	1.980	.505	521.3	1246.7	725.4
1000	985.3	546.8	2.082	.480	[illegible]	1248.7	720.3

II. PROPERTIES OF SATURATED STEAM.

Absolute Pressure per Square Inch. Lbs.	Temperatures. ° Fahr	Total Latent Heat of Steam from Water Supplied at 32° F. B.t.u.	Water Heat of Steam (to Raise Temperature of Water from 32° F.). B.t.u.	Total Heat of One Pound of Steam from Water Supplied at 32° F. B.t.u.	Density or Weight of One Cubic Foot of Steam. Lbs.	Volume of One Pound of Steam. Cu. Ft.	Relative Volume, or Cubic Feet of Steam from One Cubic Foot of Water. Rel. Vol.
122	342.4	872.8	313.0	1185.8	0.2781	3.595	224.2
123	343.0	872.3	313.7	1186.0	.2803	3.567	222.4
124	343.6	871.9	314.3	1186.2	.2824	3.541	220.8
125	344.2	871.5	314.9	1186.4	.2846	3.514	219.1
126	344.8	871.1	315.5	1186.6	.2867	3.488	217.5
127	345.4	870.7	316.1	1186.8	.2889	3.462	215.8
128	346.0	870.2	316.7	1186.9	.2910	3.436	214.3
129	346.6	869.8	317.3	1187.1	.2931	3.411	212.7
130	347.2	869.4	317.9	1187.3	.2951	3.388	211.3
131	347.8	869.0	318.5	1187.5	.2974	3.362	209.7
132	348.3	868.6	319.0	1187.6	.2996	3.338	208.1
[illegible]	348.9	868.2	319.6	1187.8	.3017	3.315	206.7
134	349.5	867.8	320.2	1188.0	.3038	3.291	205.2
135	350.1	867.4	320.8	1188.2	.3060	3.268	203.8
136	350.6	867.0	321.3	1188.3	[illegible]	3.246	202.4
137	351.2	866.6	321.9	1188.5	.3102	3.224	201.0
138	351.8	866.2	322.5	1188.7	.3123	3.201	199.6
139	352.4	865.8	323.1	1188.9	.3145	3.180	198.3
140	352.9	865.4	323.6	1189.0	.3166	3.159	197.0
141	353.5	865.0	324.2	1189.2	.3187	3.138	195.6
142	354.0	864.6	324.8	1189.4	[illegible]	3.117	194.3
143	354.5	864.2	325.4	1189.6	.3230	3.096	193.1
144	355.0	863.9	325.8	1189.7	.3251	3.076	191.8
145	355.6	863.5	326.4	1189.9	.3272	3.056	190.6
146	356.1	863.1	326.9	1190.0	.3293	3.037	189.4
147	356.7	862.7	327.5	1190.2	.3315	3.017	188.1
148	357.2	862.3	328.0	1190.3	.3336	2.998	186.9
149	357.8	861.9	328.6	1190.5	.3357	2.979	185.7
150	358.3	861.5	329.2	1190.7	.3378	2.960	184.6
151	359.0	861.1	329.8	1190.9	.3400	2.941	183.4
152	359.5	860.7	330.3	1191.0	.3421	2.923	182.2
153	360.0	860.4	330.8	1191.2	.3442	2.905	181.2
154	360.5	860.0	331.4	1191.4	.3463	2.887	180.0
155	361.1	859.6	331.9	1191.5	.3484	2.870	179.0
156	361.6	859.2	332.5	1191.7	.3505	2.853	177.9
157	362.1	858.9	332.9	1191.8	.3527	2.836	176.8
158	362.6	858.5	333.5	1192.0	.3548	2.818	175.7
159	363.1	858.1	334.0	1192.1	.3569	2.802	174.7
160	363.6	857.8	334.5	1192.3	.3590	2.785	173.7
165	366.0	856.2	336.7	1192.9	.3696	2.706	168.7
170	368.2	854.5	339.2	1193.7	.3801	2.631	164.1
175	370.8	852.9	341.5	1194.4	.3905	2.579	159.7
180	372.9	851.3	343.8	1195.1	.4011	2.493	155.5
185	375.3	849.6	346.2	1195.8	.4115	2.430	151.5
190	377.5	848.0	348.5	1196.3	.4220	2.370	147.8
195	379.7	846.5	350.7	1197.2	.4324	2.318	144.2
200	381.7	845.0	352.8	1197.8	.4419	2.263	141.1

The rate at which steam is evaporated in a given boiler will depend to a considerable extent upon the temperature at which the feed-water enters it. The table on page 331 will illustrate this fact clearly and demonstrates the value of preheating feed-water in an economizer or otherwise.

B. STEAM-BOILER PRACTICE.

Fuels.—There is a large variety of fuels adapted for steam-raising. Possibly the first in order of precedence is wood, which is equal to 40 per cent. of its weight of coal, or 2.5 lbs. of wood equal 1 lb. of coal. Some say 2.25 lbs. of dry wood equal 1 lb. of good coal. The table here presented gives a comparison of some of the usual fireplace woods.

	Weight, Lbs.	Coal Equivalent, Lbs.
One cord of hickory or hard maple	4500	2000
" " " white oak	3850	1711
" " " beech, red oak, black oak	3250	1445
" " " poplar, chestnut, elm	2350	1044
" " " pine	2000	890

Sharpless assumes a coal equivalent of about 10 per cent. less than that given above.

Coal and other solid fuels vary considerably in composition, as shown by these average examples:

ANALYSES OF FUELS.

	Water.	Volatile Matter.	Fixed Carbon.	Ash.	Sulphur.
Anthracite (mixed)...	3.40	3.80	83.80	8.40	0.60
Semi-bituminous.....	1.00	20.00	73.00	5.00	1.00
Bituminous..........	1.20	32.50	60.00	5.30	1.00
Lignite.............	22.00	32.00	37.00	9.00	
Coke...............	.....	.....	89.00	10.00	0.80

	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Ash.
Wood, dry..........	50.0	6.0	41.0	1.0	2.0
Charcoal...........	75.5	2.5	12.0	...	1.0
Peat, dry and ash-free	58.0	5.7	35.0	1.2	

WEIGHT PER CUBIC FOOT OF COAL AND COKE.

	Lbs. per Cu. Ft.	Storage for Long Ton.
Anthracite coal, market sizes, loose	52–56	40–43 cu. ft.
Anthracite coal, market sizes, moderately shaken	56–60	
Anthracite coal, market size, heaped bushel, loose .	77–83	
Bituminous coal, broken, loose	47–52	43–48 "
Bituminous coal, moderately shaken ..	50–56	
Bituminous coal, heaped bushel	70–78	
Dry coke ...	23–32	80–97 "
Dry coke, heaped bushel (average 38). .	35–42	

HEATING VALUE OF SOME FUELS.

	B.t.u.
Peat, Irish, perfectly dried, ash 4 per cent	10,200
Peat, air-dried, 25 per cent moisture, ash 4 per cent.....	7,400
Wood, perfectly dry, ash 2 per cent.	7,800
Wood, 25 per cent moisture	5,800
Tanbark, perfectly dry, 15 per cent. ash	6,100
Tanbark, 30 per cent moisture	4,300
Straw, 10 per cent moisture, ash 4 per cent	5,450
Straw, dry, ash 4 per cent	6,300
Lignites	11,200

The above are approximate figures, for on such materials qualities are very variable.

Coal and coke are often measured by the bushel. The standard bushel of the American Gaslight Association is 18½ in. diam. and 8 in. deep = 2150.42 cu. in. A heaped bushel is the same plus a cone 19½ in. diam. and 6 in. high, or a total of 2747.7 cu. in. An *ordinary* heaped bushel = 1¼ struck bushels = 2688 cu. in. = 10 gallons dry measure.

Crude petroleum 7.3 lbs. per gallon.

ANTHRACITE COAL SIZES

Size and Name.	Through a Round Hole.	Over a Round Hole.
Chestnut	1¼ inches diameter	⅞ inches diameter
Pea	⅞ " "	9/16 " "
No. 1 Buckwheat	9/16 " "	⅜ " "
No. 2 " or rice	⅜ " "	3/16 " "
No. 3 " or barley	3/16 " "	3/32 " "
Dust	3/32 " "	

Comparative Values of Fuel.—The following table shows the relative values of fuel used in furnace practice, either coal or coke, with different percentages of ash, showing the influence of the latter.

Combustible, Per Cent.	Percentage of Ash.												
	2%	3%	4%	5%	6%	7%	8%	9%	10%	11%	12%	13%	14%
75	...	...	...	...	...	...	$2.83	$2.82	$2.80	$2.79	$2.77	$2.76	$2.74
76	...	...	...	...	...	...	2.88	2.86	2.84	2.83	2.81	2.79	2.78
77	...	...	...	...	...	$2.93	2.91	2.90	2.88	2.87	2.85	2.84	2.82
78	...	...	...	...	...	2.97	2.95	2.93	2.90	2.88	2.86	2.84	
79	...	...	...	...	$3.01	2.99	2.97	2.96	2.94	2.92	2.90	2.88	
80	...	...	...	...	3.06	3.04	3.02	3.00	2.98	2.96	2.94	2.92	
81	...	...	...	...	3.10	3.08	3.06	3.04	3.02	3.00	2.98		
82	...	...	...	$3.17	3.15	3.13	3.10	3.08	3.06	3.04	3.02		
83	...	...	...	3.21	3.19	3.17	3.14	3.12	3.10	3.08	3.06		
84	...	...	...	3.25	3.23	3.21	3.18	3.16	3.14	3.12			
85	...	...	$3.33	3.31	3.29	3.26	3.23	3.20	3.18				
86	...	...	3.37	3.35	3.33	3.30	3.27	3.24					
87	...	...	3.41	3.39	3.37	3.34	3.32	3.29					
88	...	$3.46	3.44	3.42	3.39	3.36	3.33						
89	...	3.49	3.47	3.45	3.43	3.41							
90	$3.54	3.52	3.51	3.50	3.48								
91	3.58	3.57	3.56	3.54	3.52								
92	3.63	3.61	3.59	3.57									
98	3.68	3.66	3.64	3.61									

Approximately 1.43 to 1.54 lbs. of petroleum of 7.3 lbs. per gallon equals 1 lb. best soft coal. It requires about 4 per cent. of the steam generated to operate the atomizing oil spray for a boiler, this being preferred to an air spray. Probably 35,000 cu. ft. of natural gas will be equal in heating value to a ton of coal.

Water Supply.—The water-pipe should be ample in size, so as not to restrict the flow should incrustations form. Bends in the pipe also reduce the delivery. Weisbach gives this formula for the loss due to friction:

$$P = f\frac{V^2}{2g} = f\frac{V^2}{64.4},$$

where P = loss in pressure, lbs. per sq. in.;

V = velocity of flow in ft. per second;

f = coefficient of friction found in the following table for various angles of bend, A:

A..	20°	40°	45°	60°	80°	90°	100°	110°	120°	130°
f..	0.02	0.06	0.079	0.158	0.32	0.426	0.546	0.674	0.806	0.934

This applies to such short bends as are found in ordinary fittings, such as 90° and 45° ells, tees, etc. A globe valve will produce a loss about equal to two 90° bends, a straightway valve about equal to one 45° bend. To use the above formula find the velocity V from the table, square this speed, and divide the result by 64.4; multiply the quotient by the tabular value of F, corresponding to the angle of the turn A.

For example, a 400-h.p. battery of boilers is to be fed through a 2-in. pipe. Allowing for fluctuations we figure 40 gallons per minute, making 244 feet per minute speed, equal to a velocity of 4.06 ft. per second. Suppose our pipe is in all 75 ft. long, we have from the second table on page 329, for 40 gallons per minute, 1.6 lbs. loss; for 75 ft. we have only 75 per cent. of this, $=1.2$ lbs. Suppose we have six right-angled ells, each giving $F=0.426$. We have then $4.06\times4.06=16.48$; divide this by $64.4=0.256$. Multiply this by $F=0.426$ lb., and as there are six ells, multiply again by 6, and we have $6\times0.426\times0.256=0.654$. The total friction in the pipe is therefore $1.2+0.654$ lbs. per sq. in. If the boiler pressure is 100 lbs. and the water-level in the boiler is 8 feet higher than the pump-suction level we have first $8\times0.433=3.464$ lbs. The total pressure on the pump-plunger then is $100+3.464+1.854=105.32$ lbs. per sq. in. If in place of six right-angled ells we had used three 45° ells, they would have cost us only $3\times0.079=0.237$ lb.; $0.237\times 0.256=0.061$.

The total friction head would have been $1.20+0.061=1.261$ and the total pressure on the plunger $100+3.464+1.261=104.73$ lbs. per sq. in., a saving over the other plan of nearly 0.6 lb.

To be accurate we ought to add a certain head in either case "to produce the velocity." But this is very small, being for velocities of:

2	3	4	5	6	8	10	12 and	18 feet per sec.
0.027	0.061	0.108	0.168	0.244	0.433	0.672	0.970 and	2.18 lbs. per sq. in.

Our results should therefore have been increased by about 0.11 lbs. It is usual, however, to use larger pipes and thus to materially reduce the frictional losses.

The weight of water varies with the temperature as given by the table by C. A. Smith on page 330.

TABLE GIVING RATE OF FLOW OF WATER, IN FEET PER MINUTE, THROUGH PIPES OF VARIOUS SIZES, FOR VARYING QUANTITIES OF FLOW.

Gallons per Minute.	Diameter, Inches.							
	¾	1	1¼	1½	2	2½	3	4
5	218	122.5	78.5	54.5	30.5	19.5	13.5	7.6
10	436	245	157	109	61	38	27	15.3
15	653	367.5	235.5	163.5	91.5	58.5	40.5	23
20	872	490	314	218	122	78	54	30.6
25	1090	612.5	392.5	272.5	152.5	97.5	67.5	38.3
30	....	735	451	327	183	117	81	46
35	....	857.5	549.5	381.5	213.5	136.5	94.5	53.6
40	....	980	628	436	244	156	108	61.3
45	....	1102.5	706.5	490.5	274.5	175.5	121.5	69
50	....	.....	785	545	305	195	135	76.6
75	....	.....	1177.5	817.5	457.5	292.5	202.5	115
100	....	.....	.....	1090	610	380	270	153.3
125	....	.....	.....	.....	762.5	487.5	337.5	191.6
150	....	.....	.....	.....	915	585	405	230
175	....	.....	.....	.....	1067.5	682.5	472.5	268.5
200	....	.....	.....	.....	1220	780	540	306.6

LOSS IN PRESSURE DUE TO FRICTION.

POUNDS PER SQUARE INCH FOR PIPE 100 FEET LONG.

Gallons Discharged per Minute.	Diameter, Inches.							
	¾	1	1¼	1½	2	2½	3	4
5	3.3	0.84	0.31	0.12				
10	13.0	3.16	1.05	0.47	0.12			
15	28.7	6.98	2.38	0.97				
20	50.4	12.3	4.07	1.66	0.42			
25	78.0	19.0	6.40	2.62	....	0.21	0.10	
30	....	27.5	9.15	3.75	0.91			
35	....	37.0	12.4	5.05				
40	....	48.0	16.1	6.52	1.60			
45	....	....	20.2	8.15				
50	....	....	24.9	10.0	2.44	0.81	0.33	0.09
75	....	....	56.1	22.4	5.32	1.80	0.74	
100	....	....	....	39.0	9.46	3.20	1.31	0.33
125	....	....	....	....	14.9	4.89	1.99	
150	....	....	....	....	21.2	7.0	2.85	0.69
175	....	....	....	....	28.1	9.46	3.85	
200	....	....	....	....	37.5	12.47	5.02	1.22

WEIGHT OF WATER PER CUBIC FOOT AND HEAT-UNITS IN WATER BETWEEN 32° AND 212° F.

Temp., Deg. F.	Weight in Pounds per Cubic Foot.	Heat-units.	Temp., Deg. F.	Weight in Pounds per Cubic Foot.	Heat-units.	Temp., Deg. F.	Weight in Pounds per Cubic Foot.	Heat-units.
32	62.42	0.00	96	62.07	64.07	160	60.98	128.37
34	62.42	2.00	98	62.05	66.07	162	60.94	130.39
36	62.42	4.00	100	62.02	68.08	164	60.90	132.41
38	62.42	6.00	102	62.00	70.09	166	60.85	134.42
40	62.42	8.00	104	61.97	72.09	168	60.81	136.44
42	62.42	10.00	106	61.95	74.10	170	60.77	138.45
44	62.42	12.00	108	61.92	76.10	172	60.73	140.47
46	62.42	14.00	110	61.89	78.11	174	60.68	142.49
48	62.41	16.00	112	61.86	80.12	176	60.64	144.51
50	62.41	18.00	114	61.83	82.13	178	60.59	146.52
52	62.40	20.00	116	61.80	84.13	180	60.55	148.54
54	62.40	22.01	118	61.77	86.14	182	60.50	150.56
56	62.39	24.01	120	61.74	88.15	184	60.46	152.58
58	62.38	26.01	122	61.70	90.16	186	60.41	154.60
60	62.37	28.01	124	61.67	92.17	188	60.37	156.62
62	62.36	30.01	126	61.63	94.17	190	60.32	158.64
64	62.35	32.01	128	61.60	96.18	192	60.27	160.67
66	62.34	34.02	130	61.56	98.19	194	60.22	162.69
68	62.33	36.02	132	61.52	100.20	196	60.17	164.71
70	62.31	38.02	134	61.49	102.21	198	60.12	166.73
72	62.30	40.02	136	61.45	104.22	200	60.07	168.75
74	62.28	42.03	138	61.41	106.23	202	60.02	170.78
76	62.27	44.03	140	61.37	108.25	204	59.97	172.80
78	62.25	46.03	142	61.34	110.26	206	59.92	174.83
80	62.23	48.04	144	61.30	112.27	208	59.87	176.85
82	62.21	50.04	146	61.26	114.28	210	59.82	178.87
84	62.19	52.04	148	61.22	116.29	212	59.76	180.90
86	62.17	54.05	150	61.18	118.31			
88	62.15	56.05	152	61.14	120.32			
90	62.13	58.06	154	61.10	122.33			
92	62.11	60.06	156	61.06	124.35			
94	62.09	62.06	158	61.02	126.36			

Pure water at 62 deg. F. weighs 62.355 lbs. per cu. ft., or $8\frac{1}{3}$ lbs. per U. S. gallon; 7.48 gallons = 1 cu. ft. It takes 30 lbs. or 3.6 gallons of boiler feed-water for each horse-power per hour.

HEAT TRANSMITTED BY CONDENSER SURFACES PER SQUARE FOOT PER HOUR.

Surface.	B.t.u.
Smooth vertical plane	406
Vertical plane with about 80% surface in ribs or corrugations	170
Smooth vertical pipe surface	480
Vertical tube with 67% of surface in corrugations	221
Horizontal smooth tube or pipe	369
Horizontal tube with 67% of surface in corrugations	185

Note.—This table is correct for steam of 15 to 22 lbs. pressure; for exhaust-steam reduce in proportion to temperature, except for corrugated and ribbed surfaces, which lose very rapidly for low steam temperatures. For hot water, 50 per cent. of the tabular numbers is approximately correct.

PERCENTAGE OF SAVING FOR EACH DEGREE OF INCREASE IN TEMPERATURE OF FEED-WATER HEATED.

Initial Temperature of Feed.	Pressure of Steam in Boiler, Lbs. per Sq. In. above Atmosphere.										
	0	20	40	60	80	100	120	140	160	180	200
32°	.0872	.0861	.0855	.0851	.0847	.0844	.0841	.0839	.0837	.0835	.0833
40	.0878	.0867	.0861	.0856	.0853	.0850	.0847	.0845	.0843	.0841	.0839
50	.0886	.0875	.0868	.0864	.0860	.0857	.0854	.0852	.0850	.0848	.0846
60	.0894	.0883	.0876	.0872	.0867	.0864	.0862	.0859	.0856	.0855	.0853
70	.0902	.0890	.0884	.0879	.0875	.0872	.0869	.0867	.0864	.0862	.0860
80	.0910	.0898	.0891	.0887	.0883	.0879	.0877	.0874	.0872	.0870	.0868
90	.0919	.0907	.0900	.0895	.0888	.0887	.0884	.0883	.0879	.0877	.0875
100	.0927	.0915	.0908	.0903	.0899	.0895	.0892	.0890	.0887	.0885	.0883
110	.0936	.0923	.0916	.0911	.0907	.0903	.0900	.0898	.0895	.0893	.0891
120	.0945	.0932	.0925	.0919	.0915	.0911	.0908	.0906	.0903	.0901	.0899
130	.0954	.0941	.0934	.0928	.0924	.0920	.0917	.0914	.0912	.0909	.0907
140	.0963	.0950	.0943	.0937	.0932	.0929	.0925	.0923	.0920	.0918	.0916
150	.0973	.0959	.0951	.0946	.0941	.0937	.0934	.0931	.0929	.0926	.0924
160	.0982	.0968	.0961	.0955	.0950	.0946	.0943	.0940	.0937	.0935	.0933
170	.0992	.0978	.0970	.0964	.0959	.0955	.0952	.0949	.0946	.0944	.0941
180	.1002	.0988	.0981	.0973	.0969	.0965	.0961	.0958	.0955	.0953	.0951
190	.1012	.0998	.0989	.0983	.0978	.0974	.0971	.0968	.0964	.0962	.0960
200	.1022	.1008	.0999	.0993	.0988	.0984	.0980	.0977	.0974	.0972	.0969
210	.1033	.1018	.1009	.1003	.0998	.0994	.0990	.0987	.0984	.0981	.0979
220	.....	.1029	.1019	.1013	.1008	.1004	.1000	.0997	.0994	.0991	.0989
230	.....	.1039	.1031	.1024	.1018	.1012	.1010	.1007	.1003	.1001	.0999
240	.....	.1050	.1041	.1034	.1029	.1024	.1020	.1017	.1014	.1011	.1009
250	.....	.1062	.1052	.1045	.1040	.1035	.1031	.1027	.1025	.1022	.1019

MAXIMUM HEIGHT WATER CAN BE LIFTED BY SUCTION AT VARIOUS DISTANCES ABOVE SEA-LEVEL.

Height Above Sea-level, in Feet.	Average Barometric Pressure.		Height of Lift, Feet.
	Inches.	Lbs. per Sq. In.	
0	30.00	14.7	33.9
100	29.89	14.6	33.8
200	29.78	14.6	33.7
300	29.68	14.5	33.6
400	29.57	14.5	33.5
500	29.46	14.4	33.3
600	29.35	14.4	33.2
700	29.25	14.3	33.1
800	29.14	14.3	32.0
900	29.04	14.2	32.9
1000	28.94	14.2	32.7
1250	28.67	14.1	32.4
1500	28.42	13.9	32.1
2000	27.91	13.7	31.6
2500	27.40	13.4	31.0
3000	26.92	13.2	30.4
3500	26.43	13.0	29.9
4000	25.96	12.7	29.4
4500	25.49	12.5	28.9
5000	25.02	12.3	28.3
6000	24.12	11.8	27.3
7000	23.28	11.4	26.3
8000	22.44	11.0	25.4
9000	21.64	10.6	24.5
10000	20.85	10.2	23.6

Note.—The heights given above are for a perfect vacuum. In practice, pumps will ordinarily lift water about eight-tenths the height given.

CHIMNEYS.

The "proportions of chimneys" vary very much according to the requirements. Every chimney should be large enough in cross-section to carry off the gases and high enough to produce sufficient draught to cause a rapid combustion. The object of a chimney being to carry off the waste gases, it naturally determines the amount of fuel that can be burnt per hour, and it is advisable to have invariably a good draught, as it can always be regulated by a damper.

Draught pressure is caused by the difference in weight between a column of hot gases in the chimney and a column of air of equal height and area outside the chimney.

Formula for finding the force of draught in inches of water for any given chimney:

$$F=H\left(\frac{7.64}{T_2}-\frac{7.95}{T_1}\right),$$

where F = force of draught in inches of water;
H = height of chimney in feet;
T_1 = absolute temperature of chimney gases $(t+460)$;
T_2 = " " " the external air (t_1+460);
t = temperature of chimney gases;
t_1 = " " external air.

Formula for finding the height of a chimney in feet for a given force of draught:

$$H=\frac{F}{\left(\frac{7.64}{T_2}-\frac{7.95}{T_1}\right)}.$$

To find the maximum force of draught for any given chimney, the external air being 60 deg. F. and the heated column being 600 deg. F., multiply the height above the grate in feet by 0.0073, and the product is the force of draught expressed in inches of water.

William Kent, in his "Mechanical Engineer's Pocket-book" (pages 734 and 736, 4th Revised Ed.), gives the following:

"The sizes corresponding to the given commercial horse-powers are believed to be ample for all cases in which the draught areas through the boiler-flues and connections are sufficient, say not less than twenty per cent. greater than the area of the chimney, and in which the draught between the boilers and chimney is not checked by long horizontal passages and right-angled bends."

Note that the figures in table p. 336 correspond to a coal consumption of 5 lbs. coal per horse-power hour. This liberal allowance is made to cover the contingencies of poor coal being used, and of boilers being driven beyond their rated capacity. In large plants with economical boilers and engines, good fuel, and other favorable conditions, which will reduce the maximum rate of coal consumption at any one time to less than 5 lbs. per h.p. per hour, the figures in the table may be multiplied by the ratio of five to the maximum expected coal consumption per horse-power per hour. Thus, with conditions which make the maximum coal consumption 2.5 lbs. per hour, the chimney 300 ft. high × 12 ft. diameter should be sufficient for 6155 × 2 = 12,310 h.p. The formula is based on the following data.

Chimney Draught.—According to the data of the Green Fuel Economizer Co.:

1. The draught power of the chimney varies as the square root of the height.

2. The retarding of the ascending gases by friction may be considered as equivalent to a diminution of the area of the chimney, or to a lining of the chimney by a layer of gas which has no velocity. The thickness of this lining is assumed to be 2 ins. for all chimneys, or the diminution of area equal to the perimeter × 2 ins. (neglecting the overlapping of the corners of the lining). Let D=diameter in feet, A = area, and E=effective area in square feet.

$$\text{For square chimneys, } E=D^2-\frac{8D}{12}=A-\frac{2}{3}\sqrt{A}.$$

$$\text{For round chimneys, } E=\frac{\pi}{4}\left(D^2-\frac{8D}{12}\right)=A-0.591\sqrt{A}.$$

For simplifying calculations, the coefficient of $\sqrt{A}$ may be taken as 0.6 for both square and round chimneys, and the formula becomes

$$E=A-0.6\sqrt{A}.$$

3. The power varies directly as this effective area E.

4. A chimney should be proportioned so as to be capable of giving sufficient draught to cause the boiler to develop much more than its rated power, in case of emergencies, or to cause the combustion of 5 lbs. of fuel per rated horse-power of boiler per hour.

5. The power of the chimney varying directly as the effective area E, and as the square root of the height H, the formula for horse-power of boiler for a given size of chimney will take the form h.p. $=CE\sqrt{H}$, in which C is a constant, the average value of which, obtained by plotting the results obtained from numerous examples in practice, the author finds to be 3.33.

The formula for horse-power then is

$$\text{h.p.}=3.33\,E\sqrt{H}, \quad \text{or} \quad \text{h.p.}=3.33(A-.6\sqrt{A})\sqrt{H}.$$

If the horse-power of boiler is given, to find the size of chimney, the height being assumed,

$$E=\frac{0.3\ \text{h.p.}}{\sqrt{H}}=A-0.6\sqrt{A}.$$

For round chimneys, diameter of chimney = diameter of E+4 ins.

For square chimneys, side of chimney = $\sqrt{E}$+4 ins.

If effective area E is taken in square feet, the diameter in inches

is $d = 13.54\sqrt{E} + 4$ ins., and the side of a square chimney in inches is $s = 12\sqrt{E} + 4$ ins.

If horse-power is given and area assumed, the height

$$H = \left(\frac{0.3 \text{ h.p.}}{E}\right)^2.$$

In proportioning chimneys the height is generally first assumed, with due consideration to the heights of surrounding buildings or hills near to the proposed chimney, the length of horizontal flues, the character of coal to be used, etc., and then the diameter required for the assumed height and horse-power is calculated by the formula or taken from the table.

From these formulæ the table on page 336 has been calculated, assuming that for each horse-power 5 lbs. of coal are burned per hour.

WEIGHT OF COAL AND STORAGE.

21 bushels coke = 1 cubic yard (English).
72 " " = 1 ton.

Cannel coal, 45 cubic feet per ton.

Coal store should equal six weeks' supply.

SPACE OCCUPIED PER TON OF DIFFERENT COALS.

		Weight per Cubic Foot.
Average anthracite	= 39 cubic feet	58.25 lbs.
" bituminous	= 43 " "	53 "
Navy allowance for storage	= 48 " "	

COKE.

23 to 32 lbs. per cu. ft.

Ton occupies from 80 to 97 cu. ft.

Coal in coking swells in bulk from 25 to 50 per cent.

Coke and coal will evaporate about equal amounts of water and about twice the amount of an equal weight of wood.

COAL—ANTHRACITE.

Actual weight about 93.5 lbs. per cu. ft.

Broken (average) 52 to 60 lbs. per cu. ft.

Ton occupies from 40 to 43 cu. ft.

COAL—BITUMINOUS.

Actual weight about 84 lbs. per cu. ft.

Broken (average) 47 to 56 lbs. per cu. ft.

About 70 to 78 lbs. per bu.

Ton occupies 43 to 48 cu. ft.

Coal when broken increases in bulk up to 75 per cent.

SIZE OF CHIMNEYS FOR STEAM-BOILERS.

FORMULA: H.p. $=3.33(A-0.6\sqrt{A})\sqrt{H}$.

Diameter, Inches.	Area, A Sq. Ft.	Effective Area, $E=A-0.6\sqrt{A}$, Sq. Ft.	Height of Chimney, Feet. Commercial Horse-power of Boiler. 50	60	70	80	90	100	110	125	150	175	200	225	250	300	Equivalent Square Chimney, Side of Square, $\sqrt{E}+4$ in.
18	1 77	.97	23	25	27	29											16
21	2 41	1 47	35	38	41	44											10
24	3 14	2 08	49	54	58	62	66										22
27	3 98	2 78	65	72	78	83	88										24
30	4 91	3 58	84	92	.00	107	113	119									27
33	5 94	4 48		115	125	133	141	149	156								30
36	7 07	5 47		141	152	163	73	182	191	204							32
39	8 30	6 57			183	'96	08	219	229	245							35
42	9 62	7 76			216	231	245	258	271	289	316						38
48	12 57	10 44				311	330	348	365	389	426						43
54	15 90	13 51					427	449	472	503	551	595					48
60	19 64	16 98					536	565	593	632	692	748					54
66	23 76	20 83						694	728	776	849	918	981				59
72	28 27	25.08						835	876	934	1023	1105	1181	1253			64
78	33 18	29.73							1038	1107	1212	1310	1400	1485	1565		70
84	33 48	34 76							1214	1294	1418	1531	1637	1736	1830	2005	75
90	41.18	40 19								1496	1639	1770	1893	2008	2116	2318	80
96	50 27	46 01								1712	1876	2027	2167	2298	2423	2654	86
102	56 75	52 23								1944	2130	2300	2459	2609	2750	3012	91
108	63 62	58 83								2090	2399	2592	2771	2939	3098	3393	96
114	70.88	65 83									2685	2900	3100	3288	3466	3797	101
120	78 54	73 22									2986	3226	3448	3657	3855	4223	107
132	95.03	89 18									3637	3929	4200	4455	4696	5144	117
144	113 10	106 72									4352	4701	5026	5331	5618	6155	128

For pounds of coal burned per hour for any given size of chimney, multiply the figures in the table by 5.

FLUE AREA REQUIRED FOR THE PASSAGE OF A GIVEN VOLUME OF AIR AT A GIVEN VELOCITY.

Volume in Cubic Feet per Minute.	Velocity in Feet per Minute.									
	300	400	500	600	700	800	900	1000	1100	1200
100	48	36	29	24	21	18	16	14	13	12
125	60	45	36	30	26	23	20	18	16	15
150	72	54	43	36	31	27	24	22	20	18
175	84	63	50	42	36	32	28	25	23	21
200	96	72	58	48	41	36	32	29	26	24
225	108	81	65	54	46	41	36	32	29	27
250	120	90	72	60	51	45	40	36	33	30
275	132	99	79	66	57	50	44	40	36	33
300	144	108	86	72	62	54	48	43	39	36
325	156	1.7	94	78	67	59	52	47	43	39
350	168	126	101	84	72	63	56	50	46	42
375	180	135	108	90	77	68	60	54	49	45
400	192	144	115	96	82	72	64	58	52	48
425	204	153	122	102	87	77	68	61	56	51
450	216	162	130	108	93	81	72	65	59	54
475	228	171	137	114	98	86	76	68	62	57
500	240	180	144	120	103	90	80	72	65	60
525	252	189	151	126	108	95	84	76	69	63
550	264	198	158	132	113	99	88	79	72	66
575	276	207	166	138	118	104	92	83	75	69
600	288	216	173	144	123	108	96	86	79	72
625	300	225	180	150	129	113	100	90	82	75
650	312	234	187	156	134	117	104	94	85	78
675	324	243	194	162	139	122	108	97	88	81
700	336	252	202	168	144	126	112	101	92	84
725	348	261	209	174	149	131	116	104	95	87
750	360	270	216	180	154	135	120	108	98	90
775	372	279	223	186	159	140	124	112	101	93
800	384	288	230	192	165	144	128	115	105	96
825	396	297	238	198	170	149	132	119	108	99
850	408	306	245	204	175	153	136	122	111	102
875	420	315	252	210	180	158	140	126	115	105
900	432	324	259	216	185	162	144	130	118	108
925	444	333	266	222	190	167	148	133	121	111
950	456	342	274	228	195	171	152	137	124	114
975	468	351	281	234	201	176	156	140	128	117
1000	480	360	288	240	206	180	160	144	131	121

FLUE AREA REQUIRED FOR THE PASSAGE OF A GIVEN VOLUME OF AIR AT A GIVEN VELOCITY—(*Continued*).

Volume in Cubic Feet per Minute.	Velocity in Feet per Minute.								
	1300	1400	1500	1600	1700	1800	1900	2000	2100
100	11	10	9.6	9	8.5	8	7.6	7.2	6.9
125	14	13	12	11.3	10.6	10	9.5	9	8.6
150	16	15	14.4	13.5	12.7	12	11.4	10.8	10.3
175	19	18	16.8	15.8	14.8	14	13.3	12.6	12
200	22	21	19.2	18	16.9	16	15.2	14.4	13.7
225	25	23	21.6	20.3	19.1	18	17.1	16.2	15.6
250	28	26	24	22.5	21.2	20	19	18	17.1
275	30	28	26.4	24.8	23.3	22	21.8	19.8	18.9
300	33	31	28.8	27	25.4	24	22.7	21.6	20.6
325	36	33	31.2	29.3	27.5	26	24.6	23.4	22.3
350	39	36	33.6	31.5	29.6	28	26.5	25.2	24
375	42	39	36	33.8	31.8	30	28.4	27	25.7
400	44	41	38.4	36	33.9	32	30.3	28.8	27.4
425	47	44	40.8	38.3	36	34	32.2	30.6	29.1
450	50	46	43.2	40.5	38.1	36	34.1	32.4	30.9
475	53	49	45.6	42.8	40.2	38	36	34.2	32.6
500	55	51	48	45	42.4	40	37.9	36	34.3
525	58	54	50.4	47.3	44.5	42	39.8	37.8	36
550	61	57	52.8	49.5	40.6	44	41.7	38.6	37.7
575	64	59	55.2	51.8	48.7	46	43.6	41.4	39.4
600	66	62	57.6	54	50.8	48	45.5	43.2	41.1
625	69	64	60	56.3	52.9	50	47.4	45	42.9
650	72	67	62.4	58.5	55.1	52	49.3	46.8	44.6
675	75	69	64.8	60.8	57.2	54	51.2	48.6	46.3
700	78	72	67.2	63	59.3	56	53.1	50.4	48
725	80	75	69.6	65.3	61.4	58	55	52.2	49.7
750	83	77	72	67.5	63.5	60	56.9	54	51.4
775	86	80	74.4	69.8	65.6	62	58.8	56.3	53.1
800	89	82	76.8	72	67.8	64	60.6	57.6	54.9
825	91	85	79.2	74.3	69.9	66	62.5	59.4	56.6
850	94	87	81.6	76.5	72	68	64.4	61.2	58.4
875	97	90	84	78.8	74	70	67.3	63	60
900	100	93	86.4	81	76.2	72	68.2	64.8	61.7
925	103	95	88.8	83.3	78.4	74	70.1	66.6	63.4
950	105	98	91.2	85.5	80.5	76	72	68.4	65.1
975	108	100	93.6	87.8	82.6	78	73.9	70.2	66.8
1000	111	103	96	90	84.7	80	75.8	72	68.7

FLUE AREA REQUIRED FOR THE PASSAGE OF A GIVEN VOLUME OF AIR AT A GIVEN VELOCITY—(*Continued*).

Volume in Cubic Feet per Minute.	Velocity in Feet per Minute.								
	2200	2300	2400	2600	2700	2800	2900	3000	3100
100	6.6	6.3	6	5.5	5.3	5.1	5	4.8	4.6
125	8.2	7.8	7.5	6.9	6.7	6.4	6.2	6	5.8
150	9.8	9.4	9	8	8	7.7	7.5	7.2	7
175	11.5	11	10.5	9.7	9.3	9	8.7	8.4	8.1
200	13.1	12.5	12	11.1	10.7	10.3	9.9	9.6	9.3
225	14.7	14.1	13.5	12.5	12	11.6	11.2	10.8	10.4
250	16.4	15.7	15	13.9	13.3	12.9	12.4	12	11.6
275	18	17.2	16.5	15.2	14.7	14.1	13.7	13.2	12.8
300	19.6	18.8	18	16.6	16	15.4	14.9	14.4	13.9
325	21.3	20.6	19.5	18	17.3	16.7	16.1	15.6	15.1
350	22.9	21.9	21	19.4	18.7	18	17.4	16.8	16.3
375	24.5	23.5	22.5	20.8	20	19.3	18.6	18	17.4
400	26.2	25	24	22.2	21.3	20.6	19.8	19.2	18.6
425	27.8	26.6	25.5	23.5	22.7	21.9	21.1	20.4	19.7
450	29.5	28.2	27	24.9	24	23.1	22.3	21.6	20.9
475	31.1	29.7	28.5	26.3	25.3	24.4	23.6	22.8	22.1
500	32.7	31.3	30	27.7	26.7	25.7	24.8	24	23.2
525	34.4	32.9	31.5	29.1	28	26.9	25	25.2	24.4
550	36	34.4	33	30.5	29.3	28.3	27.3	26.4	25.5
575	37.6	36	34.5	31.9	30.7	29.6	28.5	27.6	26.7
600	39.3	37.6	36	33.2	32	30.8	29.8	28.8	27.8
625	40.9	39.1	37.5	34.6	33.3	32.1	31	30	29
650	42.5	40.7	39	36	34.7	33.4	32.2	31.2	30.2
675	44.1	42.3	40.5	37.5	36	34.7	33.5	32.4	31.3
700	45.8	43.8	42	38.8	37.3	36	34.7	33.6	32.5
725	47.4	45.4	43.5	40.2	38.7	37.3	36	34.8	33.6
750	49.1	47	45	41.5	40	38.6	37.2	36	34.8
775	50.7	48.5	46.5	42.9	41.3	39.9	38.5	37.2	36
800	52.4	50.1	48	44.3	42.7	41.2	39.7	38.4	37.1
825	54	51.7	49.5	45.7	44	42.4	40.9	39.6	38.3
850	55.6	53.2	51	47.1	45.3	43.7	42.2	40.8	39.4
875	57.3	54.8	52.5	48.5	46.7	45	43.4	42	40.6
900	58.9	56.3	54	49.9	48	46.3	44.6	43.2	41.8
925	60.5	57.9	55.5	51.3	49.3	47.6	46	44.4	42.9
950	62.2	59.5	57	52.6	50.7	48.8	47.1	45.6	44.1
975	63.8	61.0	58.5	54	52	50.2	48.4	46.8	45.3
1000	66	62.6	60	55.4	53.3	51.4	49.6	48	46.4

PERCENTAGE OF THE TOTAL HEAT VALUE OF THE COAL REPRESENTED BY THE VARYING AMOUNTS OF CO_2 IN FLUE-GAS.*

CO_2, Per Cent.	Heat Value of Coal, Per Cent.
2	5.3
3	8.0
4	10.8
5	13.7
6	16.6
7	19.6
8	23.0
9	26.5
10	30.0

* From H. H. Campbell's work on the Manufacture of Iron and Steel, page 243.

CHAPTER XXI.

MATHEMATICAL TABLES.

DIMENSIONS OF CIRCLES, POWERS, AND ROOTS.

Number or Diameter.	Circumference.	Circular Area.	Square.	Cube.	Square Root.	Cube Root.
1	3.1416	0.7854	1	1	1.000	1.000
2	6.2832	3.1416	4	8	1.414	1.259
3	9.4248	7.0686	9	27	1.732	1.442
4	12.57	12.57	16	64	2.000	1.587
5	15.71	19.63	25	125	2.236	1.709
6	18.85	28.27	36	216	2.449	1.817
7	21.99	38.48	49	343	2.645	1.912
8	25.13	50.27	64	512	2.828	2.000
9	28.27	63.62	81	729	3.000	2.080
10	31.42	78.54	100	1000	3.162	2.154
11	34.56	95.03	121	1331	3.316	2.223
12	37.70	113.10	144	1728	3.464	2.289
13	40.84	132.73	169	2197	3.605	2.351
14	43.98	153.94	196	2744	3.741	2.410
15	47.12	176.71	225	3375	3.872	2.466
16	50.26	201.06	256	4096	4.000	2.519
17	53.41	226.98	289	4913	4.123	2.571
18	56.55	254.47	324	5832	4.242	2.620
19	59.69	283.53	361	6859	4.358	2.668
20	62.83	314.16	400	8000	4.472	2.714
21	65.97	346.36	441	9261	4.582	2.758
22	69.11	380.13	484	10648	4.690	2.802
23	72.26	415.48	529	12167	4.795	2.843
24	75.40	452.39	576	13824	4.898	2.884
25	78.54	490.87	625	15625	5.000	2.924
26	81.68	530.93	676	17576	5.099	2.962
27	84.82	572.56	729	19683	5.196	3.000
28	87.96	615.75	784	21952	5.291	3.036
29	91.11	660.52	841	24389	5.385	3.072
30	94.25	706.86	900	27000	5.477	3.107
31	97.39	754.77	961	29791	5.567	3.141
32	100.53	804.25	1024	32768	5.656	3.174
33	103.67	855.30	1089	35937	5.744	3.207

DIMENSIONS OF CIRCLES, POWERS, AND ROOTS—(*Continued*).

Number or Diameter.	Circumference.	Circular Area.	Square.	Cube.	Square Root.	Cube Root.
34	106.81	907.92	1156	39304	5.830	3.239
35	109.96	962.11	1225	42875	5.916	3.271
36	113.10	1017.88	1296	46656	6.000	3.301
37	116.24	1075.21	1369	50653	6.082	3.332
38	119.38	1134.11	1444	54872	6.164	3.361
39	122.52	1194.59	1521	59319	6.244	3.391
40	125.66	1256.64	1600	64000	6.326	3.419
42	131.95	1385.44	1764	74088	6.480	3.476
44	138.23	1520.53	1936	85184	6.633	3.530
46	144.51	1661.90	2116	97336	6.782	3.583
48	150.80	1809.56	2304	110592	6.928	3.634
50	157.08	1963.50	2500	125000	7.071	3.684
52	163.36	2123.72	2704	140608	7.211	3.732
54	169.65	2290.22	2916	157464	7.348	3.779
56	175.93	2463.01	3136	175616	7.483	3.825
58	182.21	2642.08	3364	195112	7.615	3.870
60	188.50	2827.43	3600	216000	7.745	3.914
62	194.78	3019.07	3844	238328	7.874	3.957
64	201.06	3216.99	4096	262144	8.000	4.000
66	207.34	3421.19	4356	287496	8.124	4.041
68	213.63	3631.68	4624	314432	8.246	4.081
70	219.91	3848.45	4900	343000	8.366	4.121
72	226.19	4071.50	5184	373248	8.485	4.160
74	232.48	4300.84	5476	405224	8.602	4.198
76	238.76	4536.46	5776	438976	8.717	4.235
78	245.04	4778.36	6084	474552	8.831	4.272
80	251.33	5026.55	6400	512000	8.944	4.308
82	257.61	5281.02	6724	551368	9.055	4.344
84	263.89	5541.77	7056	592704	9.165	4.379
86	270.18	5808.80	7396	636056	9.273	4.414
88	276.46	6082.12	7744	681472	9.380	4.447
90	282.74	6361.73	8100	729000	9.486	4.481
92	289.03	6647.61	8464	778688	9.591	4.514
94	295.31	6939.78	8836	830584	9.695	4.546
96	301.59	7238.23	9216	884736	9.797	4.578
98	307.88	7542.96	9604	941192	9.899	4.610
100	314.16	7853.98	10000	1000000	10.000	4.641
102	320.41	8171.28	10404	1061208	10.099	4.672
104	326.73	8494.87	10816	1124864	10.198	4.702
106	333.01	8824.73	11236	1191016	10.295	4.732
108	339.29	9160.88	11664	1259712	10.392	4.762
110	345.57	9503.32	12100	1331000	10.488	4.791
112	351.86	9852.03	12544	1404928	10.583	4.820
114	358.14	10207.03	12996	1481544	10.677	4.848
116	364.42	10568.32	13456	1560896	10.770	4.876
118	370.71	10935.88	13924	1643032	10.862	4.904
120	376.99	11309.73	14400	1728000	10.954	4.932
122	383.27	11689.87	14884	1815848	11.045	4.959

TABLE OF DIAMETERS, CIRCUMFERENCES, AND AREAS OF CIRCLES, AND SIDES OF EQUAL SQUARES.

Diam.	Circumference.	Area.	Sides of Equal Square.	Diam.	Circumference.	Area.	Sides of Equal Square.
				11	34.557	95.033	9.7482
¼	0.7854	0.0490	0.2215	11¼	35.343	99.402	9.9698
½	1.5708	.1963	.4431	11½	36.128	103.869	10.191
¾	2.3562	.4417	.6646	11¾	36.913	108.434	10.413
1	3.1416	.7854	.8862	12	37.699	113.097	10.634
1¼	3.9270	1.2271	1.1077	12¼	38.484	117.859	10.856
1½	4.7124	1.7671	1.3293	12½	39.270	122.718	11.077
1¾	5.4978	2.4052	1.5508	12¾	40.055	127.676	11.299
2	6.2832	3.1416	1.7724	13	40.840	132.732	11.520
2¼	7.0686	3.9760	1.9939	13¼	41.626	137.886	11.742
2½	7.8540	4.9087	2.2155	13½	42.411	143.139	11.963
2¾	8.6394	5.9395	2.4370	13¾	43.197	148.489	12.185
3	9.4248	7.0686	2.6586	14	43.982	153.938	12.406
3¼	10.210	8.2957	2.8801	14¼	44.767	159.485	12.628
3½	10.995	9.6211	3.1017	14½	45.553	165.130	12.850
3¾	11.781	11.044	3.3232	14¾	46.338	170.873	13.071
4	12.566	12.566	3.5448	15	47.124	176.715	13.293
4¼	13.351	14.186	3.7663	15¼	47.909	182.654	13.514
4½	14.137	15.904	3.9880	15½	48.694	188.692	13.736
4¾	14.922	17.720	4.2095	15¾	49.480	194.828	13.957
5	15.708	19.635	4.4310	16	50.265	201.062	14.174
5¼	16.493	21.647	4.6525	16¼	51.051	207.394	14.400
5½	17.278	23.758	4.8741	16½	51.836	213.825	14.622
5¾	18.064	25.967	5.0956	16¾	52.621	220.353	14.843
6	18.849	28.274	5.3172	17	53.407	226.980	15.065
6¼	19.635	30.697	5.5388	17¼	54.192	233.705	15.286
6½	20.420	33.183	5.7603	17½	54.978	240.528	15.508
6¾	21.205	35.784	5.9819	17¾	55.763	247.450	15.730
7	21.991	38.484	6.2034	18	56.548	254.469	15.951
7¼	22.776	41.282	6.4350	18¼	57.334	261.587	16.173
7½	23.562	44.178	6.6465	18½	58.119	268.803	16.394
7¾	24.347	47.173	6.8681	18¾	58.905	276.117	16.616
8	25.132	50.265	7.0897	19	59.690	283.529	16.837
8¼	25.918	53.456	7.3112	19¼	60.475	291.039	17.060
8½	26.703	56.745	7.5328	19½	61.261	298.648	17.280
8¾	27.489	60.132	7.7544	19¾	62.046	305.355	17.502
9	28.274	63.617	7.9760	20	62.832	314.160	17.724
9¼	29.059	67.200	8.1974	20¼	63.617	322.063	17.945
9½	29.845	70.882	8.4190	20½	64.402	330.064	18.167
9¾	30.630	74.662	8.6405	20¾	65.188	338.163	18.388
10	31.416	78.540	8.8620	21	65.973	346.361	18.610
10¼	32.201	82.516	9.0836	21¼	66.759	354.657	18.831
10½	32.986	86.590	9.3051	21½	67.544	363.051	19.053
10¾	33.772	90.762	9.5267	21¾	68.329	371.543	19.274

TABLE OF DIAMETERS, CIRCUMFERENCES, AND AREAS OF CIRCLES, AND SIDES OF EQUAL SQUARES—*(Continued)*.

Diam.	Circumference.	Area.	Sides of Equal Square.	Diam.	Circumference.	Area.	Sides of Equal Square.
22	69.115	380 133	19.496	33	103.672	855.300	29 244
22¼	69.900	388 822	19.718	33¼	104.458	868.308	29.466
22½	70.686	397.608	19.939	33½	105.243	881.415	29.687
22¾	71.471	406.493	20.161	33¾	106 029	894.619	29 909
23	72.256	415.476	20.382	34	106 814	907.922	30.131
23¼	73.042	424.557	20.604	34¼	107 599	921.323	30 352
23½	73.827	433.731	20.825	34½	108.385	934.822	30.574
23¾	74.613	443.014	21.047	34¾	109.170	948.419	30.795
24	75.398	452.390	21.268	35	109.956	962.115	31.017
24¼	76.183	461.864	21.490	35¼	110.741	[redacted]	31.238
24½	76.969	471.436	21.712	35½	111.526	989.800	31.460
24¾	77.754	481.106	21.933	35¾	112.312	1003 79	31.681
25	78.540	490.875	22.155	36	113.097	1017.87	31.903
25¼	79.325	500.741	22.376	36¼	113.883	1032.06	32.124
25½	80.110	510.706	22.598	36½	114 668	1046.39	32.349
25¾	80.896	520.769	22.819	36¾	115.453	1060.73	32.567
26	81.681	530.930	23 041	37	116 239	1075.21	32.789
26¼	82.467	541.189	23 262	37¼	117.024	1089.79	33.011
26½	83 252	551.547	23.484	37½	117.810	1104.46	33.232
26¾	84.037	562.002	23 708	37¾	118.595	1119.24	33.454
27	84 823	672 556	23.927	38	119.380	1134.11	33 675
27¼	85.608	583.208	24.149	38¼	120.166	1149.08	33.897
27½	86.394	593.958	24.370	38½	120.951	1164.15	34 118
27¾	87.179	604 807	24.592	38¾	121.737	1179.32	34 340
28	87.964	615.763	24 813	39	122.522	1194.59	34.561
28¼	88.750	626.798	25.035	39¼	123.307	1209.95	34 783
[redacted]½	89.535	637.941	25 256	39½	124.093	1225.42	35.005
28¾	90.321	649.182	25.478	39¾	124.878	1240.98	35 226
29	91.106	660.521	25 699	40	125.664	1256.64	35.448
29¼	91.891	671 958	25.921	40¼	126.449	1272.39	35 669
29½	92.677	683.494	26.143	40½	127.234	1288.25	35 891
29¾	93.462	695.128	26.364	40¾	128.020	1304.20	36.112
30	94.248	706.860	26.586	41	128.805	1320.25	36 334
30¼	95.033	718 690	26 807	41¼	129.591	1336.40	36.555
30½	95.818	730.618	27.029	41½	130.376	1352.65	36.777
30¾	96.604	742 644	27.250	41¾	131.161	1369.00	36 999
31	97.389	754.769	27.472	42	131.947	1385.44	37.220
31¼	98.175	766.992	27.693	42¼	132.732	1401 98	37.442
31½	98.968	779 313	27.915	42½	133.518	1418.62	37.663
31¾	99.745	791.732	28.136	42¾	134.303	1435.36	37.885
32	100.531	804.249	28.358	43	135.088	1452.20	38.106
32¼	101.316	816.865	28.580	43¼	135.874	1469.13	38.328
32½	102.102	829.578	28.801	43½	136.659	1486.17	38.549
32¾	102.887	842.390	29.023	43¾	137.445	1503.30	38.771

TABLE OF DIAMETERS, CIRCUMFERENCES, AND AREAS OF CIRCLES, AND SIDES OF EQUAL SQUARES—(*Continued*).

Diam.	Circumference.	Area.	Sides of Equal Square.	Diam.	Circumference.	Area.	Sides of Equal Square.
44	138.230	1520.53	38.993	55	172.788	2375.83	48.741
44¼	139.015	1537.86	39.214	55¼	173.573	2397.48	48.962
44½	139.801	1555.28	39.436	55½	174.358	2419.22	49.184
44¾	140.586	1572.81	39.657	55¾	175.144	2441.07	49.405
45	141.372	1590.43	39.879	56	175.929	2463.01	49.627
45¼	142.157	1608.15	40.110	56¼	176.715	2485.05	49.848
45½	142.942	1625.97	40.322	56½	177.500	2507.19	50.070
45¾	143.728	1643.89	40.543	56¾	178.285	2529.42	50.291
46	144.513	1661.90	40.765	57	179.071	2551.76	50.513
46¼	145.299	1680.01	40.986	57¼	179.856	2574.19	50.735
46½	146.084	1698.23	41.208	57½	180.642	2596.72	50.956
46¾	146.869	1716.54	41.429	57¾	181.427	2619.35	51.178
47	147.655	1734.94	41.651	58	182.212	2642.08	51.399
47¼	148.440	1753.45	41.873	58¼	182.998	2664.91	51.621
47½	149.226	1772.05	42.094	58½	183.783	2687.83	51.842
47¾	150.011	1790.76	42.316	58¾	184.569	2710.85	52.064
48	150.796	1809.56	42.537	59	185.354	2733.97	52.285
48¼	151.582	1828.46	42.759	59¼	186.139	2757.19	52.507
48½	152.367	1847.45	42.980	59½	186.925	2780.51	52.725
48¾	153.153	1866.55	43.202	59¾	187.710	2803.92	52.950
49	153.938	1885.74	43.423	60	188.496	2827.44	53.172
49¼	154.723	1905.03	43.645	60¼	189.281	2851.45	53.393
49½	155.509	1924.42	43.867	60½	190.066	2874.76	53.615
49¾	156.294	1943.91	44.088	60¾	190.852	2898.56	53.836
50	157.080	1963.50	44.310	61	191.637	2922.47	54.048
50¼	157.865	1983.18	44.531	61¼	192.423	2946.47	54.279
50½	158.650	2002.96	44.753	61½	193.208	2970.57	54.501
50¾	159.436	2022.84	44.974	61¾	193.993	2994.77	54.723
51	160.221	2042.82	45.196	62	194.779	3019.07	54.944
51¼	161.207	2062.90	45.417	62¼	195.564	3043.47	55.166
51½	161.792	2083.07	45.639	62½	196.350	3067.96	55.387
51¾	162.577	2103.34	45.861	62¾	197.135	3092.56	55.609
52	163.363	2123.72	46.082	63	197.920	3117.25	55.830
52¼	164.148	2144.19	46.304	63¼	198.706	3142.04	56.052
52½	164.934	2164.75	46.525	63½	199.491	3166.92	56.273
52¾	165.719	2185.42	46.747	63¾	200.277	3191.91	56.495
53	166.504	2206.18	46.968	64	201.062	3216.99	56.716
53¼	167.290	2227.05	47.190	64¼	201.847	3242.17	56.931
53½	168.075	2248.01	47.411	64½	202.633	3267.46	57.159
53¾	168.861	2269.06	47.633	64¾	203.218	3292.83	57.381
54	169.646	2290.22	47.853	65	204.204	3318.31	57.603
54¼	170.431	2311.48	48.076	65¼	204.989	3343.88	57.824
54½	171.217	2332.83	48.298	65½	205.774	3369.56	58.046
54¾	172.002	2354.28	48.519	65¾	206.560	3395.33	58.267

TABLE OF DIAMETERS, CIRCUMFERENCES AND AREAS OF CIRCLES AND SIDES OF EQUAL SQUARES—*Continued.*

Diam.	Circumference	Area	Sides of Equal Squares	Diam.	Circumference	Area	Sides of Equal Squares
66	207.345	3421.20	58.490	77	241.903	4656.63	68.239
66¼	208.131	3447.16	58.711	77¼	242.688	4686.92	68.459
66½	208.916	3473.23	58.932	77½	243.474	4717.30	68.681
66¾	209.701	3499.39	59.154	77¾	244.259	4747.79	68.902
67	210.487	3525.66	59.377	78	245.044	4778.37	69.124
67¼	211.272	3552.01	59.598	78¼	245.830	4809.05	69.345
67½	212.058	3578.47	59.819	78½	246.615	4839.83	69.566
67¾	212.843	3605.03	60.040	78¾	247.401	4870.70	69.788
68	213.628	3631.68	60.262	79	248.186	4901.68	70.009
68¼	214.414	3658.44	60.483	79¼	248.971	4932.75	70.231
68½	215.199	3685.29	60.704	79½	249.757	4963.92	70.453
68¾	215.985	3712.24	60.926	79¾	250.542	4995.19	70.674
69	216.770	3739.28	61.147	80	251.328	5026.56	70.896
69¼	217.556	3766.43	61.369	80¼	252.113	5058.01	71.119
69½	218.341	3793.67	61.591	80½	252.898	5089.58	71.339
69¾	219.126	3821.02	61.812	80¾	253.684	5121.24	71.562
70	219.912	3848.46	62.034	81	254.469	5153.00	71.782
70¼	220.697	3875.99	62.255	81¼	255.255	5184.86	72.005
70½	221.482	3903.63	62.477	81½	256.040	5216.82	72.225
70¾	222.268	3931.36	62.698	81¾	256.825	5248.87	72.449
71	223.053	3959.20	62.920	82	257.611	5281.02	72.668
71¼	223.839	3987.13	63.141	82¼	258.396	5313.27	72.892
71½	224.624	4015.16	63.363	82½	259.182	5345.62	73.111
71¾	225.409	4043.28	63.584	82¾	259.967	5370.07	73.335
72	226.195	4071.51	63.806	83	260.753	5410.62	73.554
72¼	226.980	4099.83	64.028	83¼	261.538	5443.26	73.778
72½	227.766	4128.25	64.249	83½	262.323	5476.00	73.997
72¾	228.551	4156.77	64.471	83¾	263.109	5508.84	74.221
73	229.336	4185.39	64.692	84	263.894	5541.78	74.440
73¼	230.122	4212.11	64.914	84¼	264.679	5574.81	74.664
73½	230.907	4242.92	65.135	84½	265.465	5607.95	74.884
73¾	231.693	4271.83	65.357	84¾	266.250	5641.18	75.107
74	232.478	4300.85	65.578	85	267.036	5674.51	75.327
74¼	233.263	4329.95	65.800	85¼	267.821	5707.94	75.550
74½	234.049	4359.16	66.022	85½	268.606	5741.47	75.770
74¾	234.834	4388.47	66.243	85¾	269.392	5775.09	75.994
75	235.620	4417.87	66.465	86	270.177	5808.81	76.213
75¼	236.405	4447.37	66.686	86¼	270.963	5842.63	76.437
75½	237.190	4476.97	66.908	86½	271.748	5876.55	76.656
75¾	237.976	4506.67	67.129	86¾	272.533	5910.57	76.880
76	238.761	4536.47	67.351	87	273.319	5944.69	77.099
76¼	239.547	4566.36	67.572	87¼	274.104	5978.90	77.323
76½	240.332	4596.35	67.794	87½	274.890	6013.21	77.542
76¾	241.117	4626.44	68.016	87¾	275.675	6047.62	77.766

TABLE OF DIAMETERS, CIRCUMFERENCES, AND AREAS OF CIRCLES, AND SIDES OF EQUAL SQUARES—(*Continued*).

Diam.	Circumference.	Area.	Sides of Equal Square.	Diam.	Circumference.	Area.	Sides of Equal Square.
88	276.460	6018.13	77.985	99	311.018	7697.70	87.736
88¼	277.246	6116.71	78.209	99¼	311.803	7736.62	87.958
88½	278.031	6151.44	78.428	99½	312.589	7775.65	88.179
88¾	278.817	6186.25	78.652	99¾	313.374	7814.79	88.401
89	279.602	6221.15	78.871	100	314.160	7854.00	88.622
89¼	280.387	6256.15	79.095	100¼	314.945	7893.31	88.844
89½	281.173	6291.25	79.315	100½	315.730	7932.73	89.065
89¾	281.958	6326.44	79.538	100¾	316.516	7972.21	89.287
90	282.744	6361.74	79.758	101	317.301	8011.86	89.508
90¼	283.529	6397.13	79.982	101¼	318.087	8051.57	89.730
90½	284.314	6432.62	80.201	101½	318.872	8091.38	89.952
90¾	285.100	6468.21	80.424	101¾	319.657	8131.29	90.173
91	285.885	6503.89	80.644	102	320.443	8171.30	90.395
91¼	286.671	6539.68	80.868	102¼	321.228	8211.40	90.616
91½	287.456	6573.56	81.087	102½	322.014	8251.60	90.838
91¾	288.241	6611.54	81.311	102¾	322.799	8291.86	91.059
92	289.027	6647.62	81.530	103	323.584	8332.30	91.281
92¼	289.812	6683.80	81.754	103¼	324.370	8372.80	91.502
92½	290.598	6720.07	81.973	103½	325.155	8413.40	91.724
92¾	291.383	6756.45	82.197	103¾	325.941	8454.09	91.946
93	292.168	6792.92	82.416	104	326.726	8494.88	92.167
93¼	292.954	6829.49	82.640	104¼	327.511	8535.77	92.389
93½	293.739	6866.16	82.859	104½	328.297	8576.76	92.610
93¾	294.535	6902.92	83.083	104¾	329.082	8617.85	92.832
94	295.310	6939.79	83.302	105	329.868	8569.03	93.053
94¼	296.095	6976.75	83.526	105¼	330.653	8700.31	93.275
94½	296.881	7013.81	83.746	105½	331.438	8741.69	93.496
94¾	297.666	7050.97	83.970	106¾	332.224	8783.17	93.718
95	298.452	7088.23	84.189	106	333.009	8824.75	93.940
95¼	299.237	7125.58	84.413	106¼	333.794	8866.42	94.161
95½	300.022	7163.04	84.632	106½	334.580	8908.20	94.383
95¾	300.808	7200.59	84.856	106¾	335.365	8950.07	94.604
96	301.593	7238.24	85.077	107	306.151	8992.04	94.826
96¼	302.379	7275.99	85.299	107¼	306.933	9034.11	95.047
96½	303.164	7313.84	85.520	107½	337.722	9076.27	95.269
96¾	303.949	7351.78	85.742	107¾	338.506	9118.54	95.491
97	304.735	7389.82	85.964	108	339.292	9160.90	95.712
97¼	305.520	7427.96	86.185	108¼	340.077	9203.36	95.534
97½	306.306	7466.20	86.407	108½	340.863	9245.92	96.155
97¾	307.091	7504.54	86.628	108¾	341.648	9288.58	96.377
98	307.876	7542.98	86.850	109	342.434	9331.33	96.598
98¼	308.662	7581.51	87.071	109¼	343.219	9374.18	96.820
98½	309.447	7620.14	87.293	109½	344.005	9417.14	97.041
98¾	310.233	7658.87	87.514	109¾	344.789	9460.19	97.263

TABLE OF DIAMETERS, CIRCUMFERENCES, AND AREAS OF CIRCLES, AND SIDES OF EQUAL SQUARES—(*Continued*).

Diam.	Circumference.	Area.	Sides of Equal Square.	Diam.	Circumference.	Area.	Sides of Equal Square.
66	207.345	3421.20	58.489	77	241.903	4656.63	68.237
66¼	208.131	3447.16	58.710	77¼	242.688	4686.92	68.459
66½	208.916	3473.23	58.932	77½	243.474	4717.30	68.680
66¾	209.701	3499.39	59.154	77¾	244.259	4747.79	68.902
67	210.487	3525.66	59.375	78	245.044	4778.37	69.123
67¼	211.272	3552.01	59.597	78¼	245.830	4809.05	69.345
67½	212.058	3578.47	59.818	78½	246.615	4839.83	69.566
67¾	212.843	3605.03	60.040	78¾	247.401	4870.70	69.788
68	213.628	3631.68	60.261	79	248.186	4901.68	70.009
68¼	214.414	3658.44	60.483	79¼	248.971	4832.75	70.231
68½	215.199	3685.29	60.704	79½	249.757	4963.92	70.453
68¾	215.985	3712.24	60.926	79¾	250.542	4995.19	70.674
69	216.770	3739.28	61.147	80	251.328	5026.56	70.869
69¼	217.555	3766.43	61.369	80¼	252.113	5058.01	71.119
69½	218.341	3793.67	61.591	80½	252.898	5089.58	71.339
69¾	219.126	3821.02	61.812	80¾	253.684	5121.24	71.562
70	219.912	3848.46	62.934	81	254.469	5153.00	71.782
70¼	220.697	3875.99	62.255	81¼	255.255	5184.86	72.005
70½	221.482	3903.63	62.477	81½	256.040	5216.82	72.225
70¾	222.268	3931.36	62.698	81¾	256.825	5248.87	72.449
71	223.053	3959.20	62.920	82	257.611	5281.02	72.668
71¼	223.839	3987.13	63.141	82¼	258.396	5313.27	72.892
71½	224.624	4015.16	63.363	82½	259.182	5345.62	73.111
71¾	225.409	4043.28	63.545	82¾	259.967	5370.07	73.335
72	226.195	4071.51	63.806	83	260.753	5410.62	73.554
72¼	226.980	4099.83	64.028	83¼	261.538	5443.26	73.778
72½	227.766	4128.25	64.249	83½	262.323	5476.00	73.997
72¾	228.551	4165.77	64.471	83¾	263.109	5508.84	74.221
73	229.336	4185.39	64.692	84	263.894	5541.78	74.440
73¼	230.122	4212.11	64.914	84¼	264.679	5574.81	74.664
73½	230.907	4242.92	65.135	84½	265.465	5607.95	74.884
73¾	231.693	4271.83	65.357	84¾	266.250	5641.18	75.107
74	232.478	4300.85	65.578	85	267.036	5674.51	75.327
74¼	233.263	4329.95	65.800	85¼	267.821	5707.94	75.550
74½	234.049	4359.16	66.022	85½	268.606	5741.47	75.770
74¾	234.834	4388.47	66.243	85¾	269.392	5775.09	75.994
75	235.620	4417.87	66.465	86	270.177	5808.81	76.213
75¼	236.405	4447.37	66.686	86¼	270.963	5842.63	76.437
75½	237.190	4476.97	66.908	86½	271.748	5876.55	76.656
75¾	237.976	4506.67	67.129	86¾	272.533	5910.57	76.880
76	238.761	4536.47	67.351	87	273.319	5944.69	77.099
76¼	239.547	4566.36	67.572	87¼	274.104	5978.90	77.323
76½	240.332	4596.35	67.794	87½	274.890	6013.21	77.542
76¾	241.117	4626.44	68.016	87¾	275.675	6047.62	77.766

TABLE OF DIAMETERS, CIRCUMFERENCES, AND AREAS OF CIRCLES, AND SIDES OF EQUAL SQUARES—(*Continued*)

Diam.	Circumference.	Area.	Sides of Equal Square.	Diam.	Circumference.	Area.	Sides of Equal Square.
132	414.690	13684.81	116.982	143	449.247	16060.64	126.731
132¼	415.475	13736.70	117.204	143¼	450.033	16116.85	126.952
132½	416.260	13788.68	117.425	143½	450.818	16173.15	127.174
132¾	417.046	13840.76	117.647	143¾	451.604	16229.55	127.395
133	417.831	13892.94	117.868	144	452.389	16286.05	127.617
133¼	418.617	13945.2	118.090	144¼	453.174	16334.66	127.838
133½	419.402	13997.60	118.311	144½	453.960	16399.35	128.060
133¾	420.188	14050.07	118.533	144¾	454.745	16456.14	128.281
134	420.973	14102.64	118.755	145	455.531	16513.04	128.503
134¼	421.758	14155.31	118.976	145¼	456.316	16570.03	128.725
134½	422.544	14208.08	119.198	145½	457.101	16627.11	128.946
134¾	423.329	14260.95	119.419	145¾	457.887	16684.30	129.168
135	424.115	14313.9	119.641	146	458.672	16741.59	129.389
135¼	424.900	14366.98	119.862	146¼	459.458	16798.97	129.611
135½	425.685	14420.14	120.084	146½	460.243	16856.45	129.832
135¾	426.470	14473.40	120.305	146¾	461.028	16914.03	130.054
136	427.256	14526.76	120.527	147	461.814	16971.71	130.276
136¼	428.042	14580.21	120.749	147¼	462.599	17029.48	130.497
136½	428.827	14633.77	120.970	147½	463.385	17087.36	130.719
136¾	429.612	14687.42	121.192	147¾	464.170	17145.33	130.940
137	430.398	14741.12	121.413	148	464.955	17203.40	131.162
137¼	431.183	14795.02	121.635	148¼	465.741	17261.57	131.383
137½	431.969	14848.97	121.856	148½	466.526	17319.84	131.605
137¾	432.554	14903.01	122.078	148¾	467.312	17378.20	131.826
138	433.539	14957.16	122.299	149	468.097	17436.67	132.048
138¼	434.325	15011.40	122.521	149¼	468.882	17495.22	132.270
138½	435.110	15065.74	122.743	149½	469.668	17553.89	132.491
138¾	435.896	15120.18	122.964	149¾	470.453	17612.64	132.713
139	436.681	15174.71	123.186	150	471.239	17671.50	132.934
139¼	437.466	15229.35	123.407	150¼	472.024	17730.45	133.156
139½	438.252	15284.0	123.629	150½	472.809	17789.51	133.377
139¾	439.037	15338.91	123.850	150¾	473.595	17848.66	133.599
140	439.823	15393.84	124.072	151	474.380	17907.91	133.820
140¼	440.608	15448.87	124.293	151¼	475.165	17967.2	134.042
140½	441.393	15503.99	124.515	151½	475.951	18026.7	134.264
140¾	442.179	15559.22	124.737	151¾	476.736	18086.24	134.485
141	442.964	15614.54	124.958	152	477.522	18145.8	134.707
141¼	443.750	15669.96	125.180	152¼	478.307	18205.62	134.928
141½	444.535	15725.48	125.401	152½	479.092	18265.46	135.150
141¾	445.320	15781.09	125.623	152¾	479.878	18325.3	135.371
142	446.106	15836.81	125.844	153	480.663	18385.43	135.593
142¼	446.891	15892.62	126.066	153¼	481.449	18445.56	135.814
142½	447.677	15948.53	126.287	153½	482.234	18505.79	136.036
142¾	448.462	16004.54	126.509	153¾	483.019	18566.12	136.258

TABLE OF DIAMETERS, CIRCUMFERENCES, AND AREAS OF CIRCLES, AND SIDES OF EQUAL SQUARES—(*Continued*).

Diam.	Circumference.	Area.	Sides of Equal Square.	Diam.	Circumference.	Area.	Sides of Equal Square.
110	345 575	9503 34	97.485	121	380.132	11499.04	107 334
110¼	346.360	9546 69	97.707	121¼	380.918	11546 61	107.455
110½	347 146	9589 93	97 928	121½	381.703	11594 27	107 677
110¾	347.931	9633 37	98.150	121¾	382.489	11642.03	107.898
111	348 716	9776.91	98.371	122	383.274	11689 89	108 120
111¼	349.502	9720.55	98.593	122¼	384 059	11747.85	108.341
111½	350.287	9764.29	98.814	122½	384.845	11785.91	108.563
111¾	351.073	9808.12	99.036	122¾	385.630	11834.00	108.784
112	351.858	9852.06	99.258	123	386.416	11882.32	109.006
112¼	352.643	9896.09	99.479	123¼	387.201	11930.67	109.228
112½	353.429	9940 2	99.701	123½	387.986	11979.12	109.449
112¾	354.214	9984 45	99.922	123¾	388.772	12027 66	109.671
113	355.000	10028.77	100.144	124	389.557	12076.31	109 892
113¼	355.785	10073.20	100.365	124¼	390.343	12125.07	110 114
113½	356.570	10117.72	100.587	124½	391.128	12173.90	110.335
113¾	357.356	10162.34	100.808	124¾	391.913	12222.84	110 557
114	358 141	10207.06	101.030	125	392.699	12271.88	110.778
114¼	358.927	10251.88	101.252	125¼	393.484	12321.01	111.000
114½	359 712	10296.79	101 473	125½	394.270	12370.25	111.222
114¾	360 497	10341.80	101 695	125¾	395 055	12419.58	111.443
115	361.283	10386.92	101.916	126	395.840	12469 01	111.665
115¼	362.068	10432.12	102.138	126¼	396.626	12518.54	111 886
115½	362 854	10477.43	102.359	126½	397.411	12568.17	112.108
115¾	363.639	10522.84	102.581	126¾	398.197	12617.89	112.329
116	364 424	10568.34	102.802	127	398.982	12667.72	112.551
116¼	365.210	10613 94	103.024	127¼	399.767	12717.64	112.772
116½	365.995	10659.67	103.246	127½	400 553	12767.66	112.994
116¾	366 780	10705.44	103.467	127¾	401.338	12817.78	113.216
117	367.566	10751.34	103.689	128	402 124	12868 06	113 437
117¼	368.351	10797.34	103.910	128¼	402.909	12918.31	113.659
117½	369 137	10843.43	104.132	128½	403.694	12968.72	113 860
117¾	369 922	10889 62	104 353	128¾	404 480	13019.22	114.102
118	370 708	10935 91	104.575	129	405 265	13069 84	114.323
118¼	371 493	10982.30	104.796	129¼	406 051	13120.55	114.545
118½	371.278	11028.78	105.018	129½	406 836	13171.35	114.767
118¾	371.064	11075.37	105 240	129¾	407 621	13222.26	114 988
119	373 849	11122.05	105 461	130	408.407	13273.26	115.210
119¼	374 635	11168.83	105.683	130¼	409.192	13324.36	115.431
119½	375.420	11215.71	105 904	130½	409.977	13375.56	115.653
119¾	376.205	11262.69	106.126	130¾	410.763	13426.85	115 874
120	376.991	11309 76	106.347	131	411.548	13478 25	116 096
120¼	377.776	11356 93	106 569	131¼	412 334	13529 74	116 317
120½	378.562	11404.20	106 790	131½	413 119	13581.32	116 539
120¾	379.347	11451 57	107.012	131¾	413 904	13633 02	116 761

TABLE OF DIAMETERS, CIRCUMFERENCES, AND AREAS OF CIRCLES, AND SIDES OF EQUAL SQUARES—(*Continued*).

Diam.	Circumference.	Area.	Sides of Equal Square.	Diam.	Circumference.	Area.	Sides of Equal Square.
132	414.690	13684 81	116 982	143	449.247	16060.64	126.731
132¼	415.475	13736.70	117.204	143¼	450 033	16116.85	126.952
132½	416.260	13788.6[illegible]	117.425	143½	450.818	16173.15	127.174
132¾	417.046	13840 76	117.647	143¾	451.604	16229.55	127.395
133	417.831	13892.94	117.868	144	452.389	16286.05	127.617
133¼	418.617	13945.2[illegible]	118.090	144¼	453.174	16334.66	127.838
133½	419.402	13997.60	118.311	144½	453 960	16399.35	128 060
133¾	420.188	14050.07	118.533	144¾	454.745	16456.14	128.281
134	420.973	14102.64	118.755	145	455.531	16513 04	128.503
134¼	421.758	14155.31	118.976	145¼	456.316	16570.03	128.725
134½	422.544	14208 0[illegible]	119 198	145½	457.101	16627.11	128.946
134¾	423.329	14260 95	119.419	145¾	457.887	16684.30	129.168
135	424.115	14313 9[illegible]	119 641	146	458.672	16741.59	129 389
135¼	424.900	14366.98	119 862	146¼	459 458	16798.97	129.611
135½	425 685	14420.14	120 084	146½	460.243	16856.45	129.832
135¾	426.470	14473.40	120 305	146¾	461.028	16914.03	130 054
136	427.256	14526.76	120.527	147	461.814	16971.71	130.276
136¼	428.042	14580.21	120.749	147¼	462 599	17029.48	130 497
136½	428.827	14633.77	120.970	147½	463.385	17087 36	130 719
136¾	429.612	14687.42	121.192	147¾	464 170	17145 33	130 940
137	430.398	14741.12	121.413	148	464.955	17203.40	131.162
137¼	431.183	14795 02	121 635	148¼	465.741	17261.57	131.383
137½	431.969	14848.97	121 856	148½	466 526	17319.84	131.605
137¾	432.554	14903.01	122.078	148¾	467.312	17378 20	131 826
138	433.539	14957.16	122.299	149	468.097	17436 67	132.048
138¼	434.325	15011.40	122.521	149¼	468 882	17495.22	132 270
138½	435.110	15065.74	122.743	149½	469.668	17553.89	132.491
138¾	435 896	15120.18	122.964	149¾	470 453	17612.64	132.713
139	436.681	15174.7[illegible]	123.186	150	471.239	17671.50	132 934
139¼	437.466	15229 35	123.407	150¼	472.024	17730.45	133.156
139½	438.252	15284.0[illegible]	123.629	150½	472.809	17789.51	133.377
139¾	439.037	15338.91	123.850	150¾	473.595	17848.66	133.599
140	439.823	15393.84	124.072	151	474 380	17907.91	133.820
140¼	440.608	15448.87	124.293	151¼	475.165	17967 2[illegible]	134.042
140½	441.393	15503.99	124.515	151½	475 951	18026 7[illegible]	134 264
140¾	442.179	15559.22	124.737	151¾	476 736	18086.24	134.485
141	442 964	15614 54	124.958	152	477.522	18145.8[illegible]	134.707
141¼	443.750	15669 96	125 180	152¼	478.307	18205.62	134 928
141½	444 535	15725.48	125.401	152½	479.092	18265.46	135 150
141¾	445.320	15781.09	125.623	152¾	479.878	18325.39	135.371
142	446 106	15836 81	125.844	153	480.663	18385.43	135 593
142¼	446 891	15892.62	126.066	153¼	481.449	18445.56	135 814
142½	447.677	15948.53	126.287	153½	482.234	18505.79	136.036
142¾	448 462	16004.54	126 509	153¾	483 019	18566 12	136 258

TABLE OF DIAMETERS, CIRCUMFERENCES, AND AREAS OF CIRCLES, AND SIDES OF EQUAL SQUARES—(*Continued*).

Diam.	Circumference.	Area.	Sides of Equal Square.	Diam.	Circumference.	Area.	Sides of Equal Square.
154	483.805	18626.5[illegible]	136.479	165	518.362	21382.62	146.228
154¼	484.590	18687.07	136.701	165¼	519.148	21447.36	146.449
154½	485.376	18747.69	136.922	165½	519.933	21512.30	146.671
154¾	486.161	18808.42	137.144	165¾	520.719	21577.34	146.892
155	486.946	18869.24	137.365	166	521.504	21642.48	147.114
155¼	487.932	18930.15	137.587	166¼	522.290	21707.72	147.335
155½	488.517	18991.17	137.808	166½	523.075	21773.06	147.557
155¾	489.303	19052.28	138.030	166¾	523.860	21838.49	147.779
156	490.088	19113.49	138.252	167	524.646	21904.02	148.000
156¼	490.873	19174.80	138.473	167¼	525.431	21969.65	148.222
156½	491.659	19236.21	138.695	167½	526.216	22035.08	148.443
156¾	492.444	19297.72	138.916	167¾	527.002	22101.21	148.665
157	493.230	19359.32	139.138	168	527.787	22167.13	148.886
157¼	494.015	19421.03	139.359	168¼	528.573	22233.15	149.108
157½	494.800	19482.83	139.581	168½	529.358	22299.27	149.329
157¾	495.586	19544.73	139.802	168¾	530.143	22365.49	149.551
158	496.371	19605.73	140.024	169	530.929	22431.81	149.773
158¼	497.157	19668.82	140.246	169¼	531.714	22498.22	149.994
158½	497.942	19731.02	140.467	169½	532.500	22564.74	150.216
158¾	498.727	19793.31	140.689	169¾	533.285	22631.35	150.437
159	499.513	19855.70	140.910	170	534.070	22698.06	150.659
159¼	500.298	19918.1[illegible]	141.132	170¼	534.856	22764.87	150.880
159½	501.084	19980.77	141.353	170½	535.641	22831.77	151.102
159¾	501.869	20043.4[illegible]	141.575	170¾	536.426	22898.79	151.323
160	502.654	20106.2[illegible]	141.796	171	537.212	22965.88	151.545
160¼	503.440	20169.12	142.018	171¼	537.997	23033.08	151.767
160½	504.225	20232.1[illegible]	142.240	171½	538.783	23100.38	151.988
160¾	505.011	20295.1[illegible]	142.461	171¾	539.568	23167.78	152.210
161	505.796	20358.35	142.683	172	540.353	23235.27	152.431
161¼	506.581	20421.6[illegible]	142.904	172¼	541.139	23302.87	152.653
161½	507.367	20485.00	143.126	172½	541.924	23370.56	152.874
161¾	508.152	20548.47	143.347	172¾	542.710	23438.35	153.096
162	508.938	20612.0[illegible]	143.569	173	543.495	23506.24	153.317
162¼	509.723	20675.70	143.790	173¼	544.280	23574.22	153.539
162½	510.508	20739.47	144.012	173½	545.066	23642.31	153.761
162¾	511.294	20803.33	144.234	173¾	545.851	23710.49	153.982
163	512.079	20867.2[illegible]	144.455	174	546.637	23778.77	154.204
163¼	512.865	20931.3[illegible]	144.677	174¼	547.422	23847.15	154.425
163½	513.650	20995.51	144.898	174½	548.207	23915.63	154.647
[illegible]¾	514.435	21059.76	145.120	174¾	548.993	23984.20	154.868
164	515.221	21124.12	145.341	175	549.778	24052.88	155.090
164¼	516.006	21188.57	145.563	175¼	550.564	24121.65	155.311
164½	516.792	21253.12	145.784	175½	551.349	24190.52	155.533
164¾	517.577	21317.77	146.006	175¾	552.134	24259.48	155.755

TABLE OF DIAMETERS, CIRCUMFERENCES, AND AREAS OF CIRCLES, AND SIDES OF EQUAL SQUARES—(*Continued*).

Diam.	Circumference.	Area.	Sides of Equal Square.	Diam.	Circumference.	Area.	Sides of Equal Square.
176	552.920	24328 55	155.976	188	590.619	27759.16	166 611
176¼	553.706	24397 71	156 198	188¼	591.404	27833.05	166 832
176½	554.491	24466 96	156.419	188½	592.190	27907 03	167.054
176¾	555.276	24536 34	156.641	188¾	592.975	27981 10	167 276
177	556 061	24605 80	156.862	189	593.761	28055 27	167 497
177¼	556 847	24675.35	157.084	189¼	594.546	28129 54	167.719
177½	557.632	24745 01	157.306	189½	595.331	28203.91	167 940
177¾	558.418	24814 76	157.527	189¾	596.117	28278 36	168 162
178	559.203	24884.61	157.749	190	[illegible]	28352 94	168 383
178¼	559.988	24954.56	157.970	190¼	597 687	28427.60	168 605
178½	560 774	25024 61	158.192	190½	598.473	28502 36	168 826
178¾	561.559	25094 76	158.413	190¾	599.258	28577 22	169.048
179	562.345	25165.00	158 635	191	600 044	28652 18	169 270
179¼	563.130	25235 34	158.856	191¼	600 829	28727.23	169 491
179½	563 915	25305 78	159.078	191½	601.614	28802.39	169 713
179¾	564.701	25376.32	159 299	191¾	602.400	28877 64	169 934
180	565.486	25446 96	159.521	192	603.185	[illegible]	170 156
180¼	566 272	25517.70	159.743	192¼	603.971	29028.43	170.377
180½	567.057	25588.53	159.964	192½	604.756	29103 98	170 599
180¾	567.842	25659.46	160.186	192¾	605.541	29179.62	170 820
181	568.628	25730.49	160.407	193	[illegible]	29255 37	171 042
181¼	569.413	25801 62	160.629	193¼	607.112	29331.21	171 264
181½	570 199	25872.84	160.850	193½	607.898	29407 14	171.485
181¾	570.984	25944.17	161.072	193¾	608.683	29483.18	171.707
182	571.769	26015 59	161.293	194	609.468	29559.32	171.928
182¼	572.555	26087 11	161.515	194¼	610.254	29635.65	172.150
182½	573.340	26158.73	161.737	194½	611.039	29711.88	172 371
182¾	574.126	26230 45	161.958	194¾	611.825	29788 31	172.593
183	574.911	26302.26	162 180	195	612.610	29864 84	172.814
183¼	575.696	26374 17	162.401	195¼	613.395	29941 46	173.036
183½	576 482	26446 19	162 623	195½	614.181	30018.19	173.258
183¾	577.267	26519.29	162.844	195¾	614 966	30095 01	173.479
184	578.053	26590 50	163 066	196	615 752	30171.98	173.701
184¼	578.838	26662 81	163 287	196¼	616.537	30248 96	173.922
184½	579.623	26735 21	163 509	196½	617.322	[illegible]	174 144
184¾	580.409	26807.71	163.732	196¾	618.108	30403.28	174.365
185	581.194	26880 32	163.952	197	618.893	30480.60	174.587
185¼	581.980	26953 01	164.174	197¼	619.679	30588 00	174 808
185½	582.765	27025 81	164.395	197½	620.464	30635.51	175 030
185¾	583.550	27098 71	164.617	197¾	621.249	30713.12	175 252
186	584.336	27171.70	164 838	198	622 035	30790 82	175.473
186¼	585.121	27244.79	[illegible]	198¼	622.820	30868 63	175.695
186½	585.907	27317.98	165 282	198½	[illegible]	[illegible]	175 916
186¾	586.692	27391 27	165.503	198¾	624 391	31024 53	176.138
187	587.477	27464.65	165.725	199	625 176	31102.63	176.359
187¼	588.263	27538 14	165 946	199¼	625.962	31180.82	176.581
187½	589.048	27611.72	166 168	199½	626.747	31259 12	176 802
187¾	589 834	27685.40	166.389	199¾	627.533	31337 49	177.024
				200	628 318	31415.98	177.240

DECIMAL EQUIVALENT OF AN INCH.

8ths.	$\frac{9}{16}$ = .5625	$\frac{17}{32}$ = .53125	$\frac{9}{64}$ = .140625	$\frac{37}{64}$ = .578125
$\frac{1}{8}$ = .125	$\frac{11}{16}$ = .6875	$\frac{19}{32}$ = .59375	$\frac{11}{64}$ = .171875	$\frac{39}{64}$ = .609375
$\frac{1}{4}$ = .250	$\frac{13}{16}$ = .8125	$\frac{21}{32}$ = .65625	$\frac{13}{64}$ = .203125	$\frac{41}{64}$ = .640625
$\frac{3}{8}$ = .375	$\frac{15}{16}$ = .9375	$\frac{23}{32}$ = .71875	$\frac{15}{64}$ = .234375	$\frac{43}{64}$ = .671875
$\frac{1}{2}$ = .500		$\frac{25}{32}$ = .78125	$\frac{17}{64}$ = .265625	$\frac{45}{64}$ = .703125
$\frac{5}{8}$ = .625	32ds.	$\frac{27}{32}$ = .84375	$\frac{19}{64}$ = .296875	$\frac{47}{64}$ = .734375
$\frac{3}{4}$ = .750	$\frac{1}{32}$ = .03125	$\frac{29}{32}$ = .90625	$\frac{21}{64}$ = .328125	$\frac{49}{64}$ = .765625
$\frac{7}{8}$ = .875	$\frac{3}{32}$ = .09375	$\frac{31}{32}$ = .96875	$\frac{23}{64}$ = .359375	$\frac{51}{64}$ = .796875
	$\frac{5}{32}$ = .15625		$\frac{25}{64}$ = .390625	$\frac{53}{64}$ = .828125
16ths.	$\frac{7}{32}$ = .21875	64ths.	$\frac{27}{64}$ = .421875	$\frac{55}{64}$ = .859375
$\frac{1}{16}$ = .0625	$\frac{9}{32}$ = .28125	$\frac{1}{64}$ = .015625	$\frac{29}{64}$ = .453125	$\frac{57}{64}$ = .890625
$\frac{3}{16}$ = .1875	$\frac{11}{32}$ = .34375	$\frac{3}{64}$ = .046875	$\frac{31}{64}$ = .484375	$\frac{59}{64}$ = .921875
$\frac{5}{16}$ = .3125	$\frac{13}{32}$ = .40625	$\frac{5}{64}$ = .078125	$\frac{33}{64}$ = .515627	$\frac{61}{64}$ = .953125
$\frac{7}{16}$ = .4375	$\frac{15}{32}$ = .46875	$\frac{7}{64}$ = .109375	$\frac{35}{64}$ = .546875	$\frac{63}{64}$ = .984375

LOGARITHMS OF CONVENIENT CONSTANTS.

Compiled by J. J. Clark.

Number.	Logarithm.	Reciprocal.	Logarithm.
$\pi = 3.1416$	.4971509	.318309	$\bar{1}.5028491$
$\frac{\pi}{4} = .7854$	$\bar{1}.8950909$	1.273237	.1049091
$\pi^2 = 9.86965$	.9943018	.10132	$\bar{1}.0056982$
$\sqrt{\pi} = 1.772457$	.2485755	.5641888	$\bar{1}.7514245$
$\sqrt{\frac{1}{\pi}} = .564189$	$\bar{1}.7514245$	1.772456	.2485755
$g = 32.16$	1.5073160	.0310945	$\bar{2}.4926840$
$\frac{1}{2}g = 16.08$	1.2062860	.06218906	$\bar{2}.7937140$
$2g = 64.32$	1.8083460	.01554727	$\bar{2}.1916540$
$\sqrt{2g} = 8.019974$	.9041730	.1246887	$\bar{1}.0958270$
1 cu. in. water weighs .03617 lbs.	$\bar{2}.5583485$	27.64723	1.4416515
Water-column 1″×1″×1′ weighs .43403 lbs.	$\bar{1}.6375197$	2.303988	.3624803
Water-column 1″ d.×1′ weighs .34088 lbs.	$\bar{1}.5326015$	2.933584	.4673985
1 lb. water = column 1″×1″×2.304′	.3624825	.4340278	$\bar{1}.6375175$
1 lb. water = column 1″ d.×2.9336′	.4674009	.340878	$\bar{1}.5325991$
1 cu. ft. air at 32° F. and 30″ Hg weighs .08073 lbs.	$\bar{2}.9070350$	12.387	1.0929650
1 gal. H_2O weighs 8.355 lbs.	.9219465	.11969	$\bar{1}.0780535$
1 cu. ft. H_2O contains 7.48 gal.	.8739016	.13369	$\bar{1}.1260984$
14.7	1.1673173	.06802721	$\bar{2}.8326827$
1728	3.2375437	.0005787037	$\bar{4}.7624563$
778	2.8909796	.001285347	$\bar{3}.1090204$
144	2.1583625	.00694445	$\bar{3}.8416375$
12	1.0791812	.0833333	$\bar{2}.9208188$
33000	4.5185139	.0000303	$\bar{5}.4814861$

LENGTHS OF CHORDS FOR SPACING CIRCLE WHOSE DIAMETER IS 1.

For Circles of other Diameters Multiply Length given in Table by Diameter of Circle.

No. of Spaces.	Length of Chord.	No. of Spaces.	Length of Chord.	No. of Spaces.	Length of Chord.	No. of Spaces.	Length of Chord.
		26	.1205	51	.0616	76	.0413
		27	.1161	52	.0604	77	.0408
3	.8660	28	.1120	53	.0592	78	.0403
4	.7071	29	.1081	54	.0581	79	.0398
5	.5878	30	.1045	55	.0571	80	.0393
6	.5000	31	.1012	56	.0561	81	.0388
7	.4339	32	.0980	57	.0551	82	.0383
8	.3827	33	.0951	58	.0541	83	.0378
9	.3420	34	.0923	59	.0532	84	.0374
10	.3090	35	.0896	60	.0523	85	.0370
11	.2817	36	.0872	61	.0515	86	.0365
12	.2588	37	.0848	62	.0507	87	.0361
13	.2393	38	.0826	63	.0499	88	.0357
14	.2225	39	.0805	64	.0491	89	.0353
15	.2079	40	.0785	65	.0483	90	.0349
16	.1951	41	.0765	66	.0476	91	.0345
17	.1838	42	.0747	67	.0469	92	.0341
18	.1736	43	.0730	68	.0462	93	.0338
19	.1646	44	.0713	69	.0455	94	.0334
20	.1564	45	.0698	70	.0449	95	.0331
21	.1490	46	.0682	71	.0442	96	.0327
22	.1423	47	.0668	72	.0436	97	.0324
23	.1362	48	.0654	73	.0430	98	.0321
24	.1305	49	.0641	74	.0424	99	.0317
25	.1253	50	.0628	75	.0419	100	.0314

LOGARITHM OF NUMBERS FROM 0 TO 1200.

No.	0	1	2	3	4	5	6	7	8	9	Prop.
0	0	00000	30103	47712	60206	69897	77815	84510	90309	95424	
10	00000	00432	00860	01284	01793	02119	02531	02938	03342	03743	415
11	04139	04532	04922	05308	05690	06070	06746	06819	07188	07555	379
12	07918	08279	08636	08991	09342	09691	10037	10380	10721	11059	344
13	11394	11727	12057	12385	12710	13033	13354	13672	13988	14301	323
14	14613	14922	15229	15534	15836	16137	16435	16732	17026	17319	298
15	17609	17898	18184	18468	18752	19033	19312	19590	19866	20140	281
16	20412	20683	20952	21219	21484	21748	22011	22272	22531	22789	264
17	23045	23300	23553	23805	24055	24304	24551	24797	25042	25285	249
18	25527	25768	26007	26245	26482	26717	26951	27184	27416	27646	234
19	27875	28103	28330	28556	28780	29003	29226	29447	29667	29885	222
20	30103	30320	30535	30750	30963	31175	31387	31597	31806	32015	212
21	32222	32428	32634	32838	33041	33244	33415	33646	33846	34044	202
22	34242	34439	34635	34830	35025	35218	35411	35603	35793	35984	193
23	36173	36361	36549	36736	37922	37107	37291	37475	37658	37840	185
24	38021	38202	38382	38561	38739	38917	39094	39270	39445	39620	177
25	39794	39967	40140	40312	40483	40654	40824	40993	41162	41330	170
26	41497	41664	41830	41996	42160	42325	42488	42651	42813	42975	164
27	43136	43297	43457	43616	43775	43933	44091	44248	44404	44560	158
28	44716	44871	45025	45179	45332	45484	45637	45788	45939	46090	153
29	46240	46389	46538	46687	46835	46982	47129	47276	47422	47567	148
30	47712	47857	48001	48144	48287	48430	48572	48714	48855	48966	143
31	49136	49276	49415	49554	49693	49831	49969	50106	50243	50379	138
32	50515	50651	50786	50920	51055	51189	51322	51455	51587	51720	134
33	51851	51983	52114	52244	52375	52504	52634	52763	52892	53020	130
34	53148	53275	53403	53529	53656	53782	53908	54033	54158	54283	126
35	54407	54531	54654	54777	54900	55023	55145	55267	55388	55509	122
36	55630	55751	55871	55991	56110	56229	56348	56467	56585	56703	119
37	56820	56937	57054	57171	57287	57403	57519	57634	57749	57864	116
38	57978	58093	58206	58320	58433	58546	58659	58771	58883	58995	113
39	59106	59218	59329	59439	59550	59660	59770	59879	59988	60097	110
40	60206	60314	60423	60531	60638	60746	60853	60959	61066	61172	107
41	61278	61384	61490	61595	61700	61805	61909	62014	62118	62221	104
42	62325	62428	62531	62634	62737	62839	62941	63043	63144	63246	102
43	63347	63448	63548	63649	63749	63849	63949	64048	64147	64246	99
44	64345	64444	64542	64640	64738	64836	64933	65031	65128	65225	98
45	65321	65418	65514	65610	65706	65801	65896	65992	66087	66181	96
46	66276	66370	66464	66558	66652	66745	66839	66932	67025	67117	95
47	67210	67302	67394	67486	67578	67669	67761	67852	67943	68034	92
48	68124	68215	68305	68395	68485	68574	68664	68753	68842	68931	90
49	69020	69108	69197	69285	69373	69461	69548	69636	69723	69810	88
50	69897	69984	70070	70157	70243	70329	70415	70501	70586	70672	86
51	70757	70842	70927	71012	71096	71181	71265	71349	71433	71517	84
52	71600	71684	71767	71850	71933	72016	72099	72181	72263	72346	82
53	72428	72509	72591	72673	72754	72835	72916	72997	73078	73159	81

Indices of Logarithms:
Log. 4030 = 3.60530
" 403 = 2.60530

Log. 40.3 = 1.60530
" 4.03 = .60530
" .403 = .60530

Log. .0403 = $\bar{2}$.60530
" .00403 = $\bar{3}$.60530

Find Log. of 5065
Log. of 5060 .. = 3.70415
Prop. 86 × Diff. 5 .. = 430

Log. required = 3.704580
Find number of Log. .. 3.771442
Log. of 5900 = 3.770850

Diff. 592 + Prop. 73 = 8. Diff. = 592
No. required 5908

LOGARITHM OF NUMBERS FROM 0 TO 1200—*Continued.*

No.	0	1	2	3	4	5	6	7	8	9	Prop.
54	73239	73320	73400	73480	73560	73640	[redacted]	73799	73878	73957	80
55	74036	74115	74194	74273	74351	74429	74507	74586	74663	74741	78
56	74819	74896	74974	75051	75128	75205	75282	75358	75435	75511	77
57	75587	75664	75740	75815	75891	75967	76042	76118	76193	76268	75
58	76343	76418	76492	76567	76641	[redacted]	76790	76864	76938	77012	74
59	77085	77159	77232	77305	77379	77452	77525	77597	77670	77743	73
60	77815	77887	77960	78032	78104	78176	78247	78319	78390	78462	72
61	78533	78604	78675	78746	78817	78888	78958	79029	79099	79169	71
62	79239	79309	79379	79449	79518	79588	79657	79727	79796	79865	70
63	79934	80003	80072	80140	80209	80277	80346	80414	80482	80550	69
64	80618	80686	80754	80821	80889	80956	81023	81090	81158	81224	68
65	81291	81358	81425	81491	81558	81624	81690	81757	81823	[redacted]	67
66	81954	82020	82086	82151	82217	82282	82347	82413	82478	82543	[redacted]
67	82607	82672	82737	82802	82866	82930	82995	83059	83123	83187	64
68	83251	83315	83378	83442	83506	83569	83632	83696	83759	83822	63
69	83885	83948	84011	84073	84136	84198	84261	84323	84386	84448	63
70	84510	84572	84634	84696	84757	[redacted]	84880	84942	85003	85065	62
71	85126	85187	85248	85309	85370	85431	85491	85552	85612	85673	61
72	85733	85794	85854	85914	85974	86034	86094	86153	86213	86273	60
73	86332	86392	86451	86510	86570	86629	86688	86747	86806	86864	59
74	86923	86982	87040	87099	[redacted]	87216	87274	87332	87390	87448	58
75	87506	87564	87622	87680	87737	87795	87852	87910	87967	88024	57
76	88081	88138	88195	88252	88309	88366	88423	88480	88536	88593	57
77	88649	88705	88762	[redacted]	88874	88930	88986	89042	89098	89154	56
78	89209	89265	89321	89376	89432	89487	89542	89597	89653	89708	55
79	89763	89818	89873	89927	89982	90037	90091	90146	[redacted]	[redacted]	54
80	90309	90363	90417	90472	90526	90580	90634	90687	90741	90795	54
81	90849	90902	90956	91009	91062	91116	91169	91222	91275	91328	53
82	91381	91434	91487	91540	91593	91645	91698	91751	91803	91855	53
83	91908	91960	92012	92065	92117	92169	92221	92273	[redacted]	92376	52
84	92428	92480	92531	92583	92634	92686	92737	92788	92840	92891	51
85	92942	92993	93044	93095	93146	93197	93247	93298	93349	[redacted]	51
86	93450	93500	93551	93601	93651	93702	93752	93802	93852	93902	50
87	93952	94002	94052	94101	94151	94201	94250	94300	94349	94399	49
88	94448	94498	94547	94596	94645	94694	94743	94792	94841	94890	49
89	94939	94988	95036	95085	95134	95182	95231	95279	95328	95376	48
90	95424	95472	95521	95569	95617	95665	[redacted]	95761	95809	95856	48
91	95904	95952	95999	96047	96095	96142	96190	96237	96284	96332	48
92	96379	96426	96473	96520	96567	96614	96661	96708	96755	96802	47
93	96848	96895	96942	96988	97035	97081	97128	97174	97220	97267	47
94	97313	97359	97405	97451	97497	97543	[redacted]	97635	[redacted]	97727	46
95	97772	97818	97864	97909	97955	98000	98046	98091	98137	98182	46
96	98227	98272	98318	98363	98408	98453	98498	98543	98588	98632	45
97	98677	98722	98767	98811	98856	98900	98945	98989	99034	99078	45
98	99123	99167	99211	99255	99300	99344	99388	99432	99476	99520	44
99	99564	99607	99651	99695	99739	99782	99826	99870	99913	99957	44
100	00000	00043	00087	00130	00173	00217	00260	00303	00346	[redacted]	43
101	00432	00475	00518	00561	[redacted]	00647	00689	00732	00775	00817	43
102	00860	00903	00945	00988	01030	01072	01115	01157	01199	01242	42
103	01284	01326	01368	01410	01452	01494	[redacted]	01578	[redacted]	01662	42

To multiply by logarithms add the logarithms together and find the corresponding number.

To divide by logarithms subtract one from the other.

To extract the root divide the logarithm by the index of the root and find the number corresponding to it.

To raise a number to any power multiply the logarithm by the index of the power and find the corresponding number.

LOGARITHM OF NUMBERS FROM 0 TO 1200—*Continued.*

No.	0	1	2	3	4	5	6	7	8	9	Prop.
104	01703	01745	01787	01828	01870	01912	01953	01995	02036	02078	42
105	02119	02160	02202	02243	02284	02325	02366	02407	02449	02490	41
106	02531	02572	02612	02653	02694	02735	02776	02816	02857	02898	41
107	02938	02979	03019	03060	03100	03141	03181	03222	03262	03302	41
108	03342	03383	03423	03463	03503	03543	03583	03623	03663	03703	40
109	03743	03782	03822	03862	03902	03941	03981	04021	04060	04100	40
110	04139	04179	04218	04258	04297	04336	04376	04415	04454	04493	39
111	04532	04571	04610	04650	04689	04727	04766	04805	04844	04883	39
112	04922	04961	04999	05038	05077	05115	05154	05192	05231	05269	39
113	05308	05346	05385	05423	05461	05500	05538	05576	05614	05652	38
114	05690	05729	05767	05805	05843	05881	05918	05956	05994	06032	38
115	06076	06108	06145	06183	06221	06258	06296	06333	06371	06408	38
116	06446	06483	06521	06558	06595	06633	06670	06707	06744	06781	37
117	06819	068 6	06893	06930	06967	07004	07041	07078	07115	07151	37
118	07188	07225	07262	07298	07335	07372	07408	07445	07482	07518	37
119	07555	07591	07628	07644	07700	07737	07773	07809	07846	07882	36

Involution and Evolution of Fractions by Logarithms.

In a logarithm the integer is called the *characteristic*, and the decimal portion the *mantissa.*

INVOLUTION.—The number carried from the *mantissa* to the *characteristic* being positive, must be deducted from the negative characteristic.

Example.—Find the 5th power of .05, or the value of $.05^5$.

$$\text{Log. } .05 = \bar{2}.69897$$
$$\text{then } \bar{2} \times 5 = \overline{10}$$
$$+$$
$$\text{and } .69897 \times 5 = 3.49485$$

$$\text{Then log. } .05^5 = \bar{7}.49485$$
$$\text{and } .05^5 = .0000003125$$

EVOLUTION.—If the *negative* characteristic be not divisible without a remainder by the index of the required root, the number of units sufficient to make it so divisible must be added to it, and the same number of units must also be added to the mantissa before division.

Example.—Find the value of $\sqrt[5]{.0000003125}$.

$$\text{Log. } .0000003125 = \bar{7}.49485$$
$$\text{then } 7 + 3 = 10, \text{ and } \overline{10} \div 5 = \bar{2}$$
$$\text{and } 3.49485 \div 5 = .69897$$

$$\text{Therefore log. } \sqrt[5]{.0000003125} = \bar{2}.69897 = \text{log. of } .05.$$

Proportion by Logarithms.

Add together the logarithms of the 2d and 3d terms, and from their sum subtract the logarithm of the first term, then the number corresponding to the logarithm of the remainder gives the required answer.

Example.—68.30 : 13.70 : : 79.40 : ?

$$\text{Log. } 13.70 = 1.13672$$
$$\text{Log. } 79.40 = 1.89982$$

$$\text{Sum } \quad 3.03654$$
$$\text{Log. } 68.30 = 1.83442$$

$$\text{Diff. } \quad 1.20212 = \text{log. of } 15.93.$$

The common logarithm of any number is the power to which, if 10 be raised, the said number is the result, thus:

$$10^2 = 100 \text{ therefore log.} = 2.$$
$$10^{2.42} = 263 \quad \text{“} \quad \text{“} = 2.42$$
$$10^{-2.42} = .0263 \quad \text{“} \quad \text{“} = \bar{2}.42$$

To multiply by the aid of logarithms—add the logarithms of the numbers together and find the corresponding number of the logarithm obtained.

To divide by the aid of logarithms—subtract one logarithm from the other.

To extract any root—divide the logarithm by the index of the root and find the corresponding number of the logarithm obtained.

To raise a number to any power—multiply the logarithm of the number by the index of the power, and find the corresponding number of the logarithm obtained.

To find proportion by the aid of logarithms—add together the logarithms of the second and third terms and subtract the logarithm of the first term; the answer is the corresponding number of the logarithm obtained.

VALUES OF SQUARES, CUBES, SQUARE ROOTS, AND CUBE ROOTS OF NUMBERS 1 TO 100.

No.	Square.	Cube.	Square Root.	Cube Root.	No.	Square.	Cube.	Square Root.	Cube Root.
1	1	1	1.0	1.0	51	2601	132651	7.14143	3.7084
2	4	8	1.41421	1.2599	52	2704	140608	7.21110	3.7325
3	9	27	1.73205	1.4422	53	2809	148877	7.28011	3.7563
4	16	64	2.0	1.5874	54	2916	157464	7.34847	3.7798
5	25	125	2.23607	1.7100	55	3025	166375	7.4162	3.8030
6	36	216	2.44949	1.8171	56	3136	175616	7.48331	3.8259
7	49	343	2.64575	1.9129	57	3249	185193	7.54983	3.8485
8	64	512	2.82843	2.0	58	3364	195112	7.61577	3.8709
9	81	729	3.0	2.0801	59	3481	205379	7.68115	3.8930
10	100	1000	3.16228	2.1544	60	3600	216000	7.74597	3.9149
11	121	1331	3.31662	2.2240	61	3721	226981	7.81025	3.9365
12	144	1728	3.46410	2.2894	62	3844	238328	7.87401	3.9579
13	169	2197	3.60555	2.3513	63	3969	250047	7.93725	3.9791
14	196	2744	3.74166	2.4101	64	4096	262144	8.0	4.0
15	225	3375	3.87298	2.4662	65	4225	274625	8.06226	4.0207
16	256	4096	4.0	2.5198	66	4356	287496	8.12404	4.0412
17	289	4913	4.12311	2.5713	67	4489	300763	8.18535	4.0615
18	324	5832	4.24264	2.6207	68	4624	314432	8.24621	4.0817
19	361	6859	4.35890	2.6684	69	4761	328509	8.30662	4.1016
20	400	8000	4.47214	2.7144	70	4900	343000	8.36660	4.1213
21	441	9261	4.58258	2.7589	71	5041	357911	8.42615	4.1408
22	484	10648	4.69042	2.8020	72	5184	373248	8.48528	4.1602
23	529	12167	4.79583	2.8439	73	5329	389017	8.54400	4.1793
24	576	13824	4.89898	2.8845	74	5476	405224	8.60233	4.1983
25	625	15625	5.0	2.9240	75	5625	421875	8.66025	4.2172
26	676	17576	5.09902	2.9625	76	5776	438976	8.71780	4.2358
27	729	19683	5.19615	3.0	77	5929	456533	8.77496	4.2543
28	784	21952	5.29150	3.0366	78	6084	474552	8.83176	4.2727
29	841	24389	5.38516	3.0723	79	6241	493039	8.88819	4.2908
30	900	27000	5.47723	3.1072	80	6400	512000	8.94427	4.3089
31	961	29791	5.56776	3.1414	81	6551	531441	9.0	4.3267
32	1024	32768	5.65685	3.1748	82	6724	551368	9.05539	4.3445
33	1089	35937	5.74456	3.2075	83	6889	571787	9.11043	4.3621
34	1156	39304	5.83095	3.2396	84	7056	592704	9.16515	4.3795
35	1225	42875	5.91608	3.2711	85	7225	614125	9.21954	4.3968
36	1296	46656	6.0	3.3019	86	7396	636056	9.27362	4.4140
37	1369	50653	6.08276	3.3322	87	7569	658503	9.32738	4.4310
38	1444	54872	6.16441	3.3620	88	7744	681472	9.38083	4.4480
39	1521	59319	6.245	3.3912	89	7921	704969	9.43398	4.4647
40	1600	64000	6.32456	3.4200	90	8100	729000	9.48683	4.4814
41	1681	68921	6.40312	3.4482	91	8281	753571	9.53939	4.4979
42	1764	74088	6.48074	3.4760	92	8464	778688	9.59166	4.5144
43	1849	79507	6.55744	3.5034	93	8649	804357	9.64365	4.5307
44	1936	85184	6.63325	3.5303	94	8836	830584	9.69536	4.5468
45	2025	91125	6.70820	3.5569	95	9025	857375	9.74679	4.5629
46	2116	97336	6.78233	3.5830	96	9216	884736	9.79796	4.5789
47	2209	103823	6.85565	3.6088	97	9409	912673	9.84886	4.5947
48	2304	110592	6.92820	3.6342	98	9604	941192	9.89949	4.6104
49	2401	117649	7.0	3.6593	99	9801	970299	9.94987	4.6261
50	2500	125000	7.07107	3.6840	100	10000	1000000	10.0	4.6416

VALUES OF $n\pi$ AND $n^2\frac{\pi}{4}$ FOR NUMBERS FROM 1 TO 100.

n	$n\pi$	$n^2\frac{\pi}{4}$	n	$n\pi$	$n^2\frac{\pi}{4}$	n	$n\pi$	$n^2\frac{\pi}{4}$
1.0	3.142	0.7854	26.0	81.681	530.93	52.0	163.36	2123.72
1.5	4.712	1.7672	26.5	83.252	551.55	53.0	166.50	2206.19
2.0	6.283	3.1416	27.0	84.823	572.56	54.0	169.64	2290.22
2.5	7.854	4.9087	27.5	86.394	593.96	55.0	172.78	2375.83
3.0	9.425	7.0686	28.0	87.965	615.75	56.0	175.93	2463.01
3.5	10.996	9.6211	28.5	89.535	637.94	57.0	179.07	2551.76
4.0	12.566	12.566	29.0	91.106	660.52	58.0	182.21	2642.08
4.5	14.137	15.904	29.5	92.677	683.49	59.0	185.35	2733.97
5.0	15.708	19.635	30.0	94.248	706.86	60.0	188.49	2827.44
5.5	17.279	23.758	30.5	95.819	730.62	61.0	191.63	2922.47
6.0	18.850	28.274	31.0	97.389	754.77	62.0	194.77	3019.07
6.5	20.420	33.183	31.5	98.960	779.31	63.0	197.92	3117.25
7.0	21.991	38.485	32.0	100.53	804.25	64.0	201.06	3216.99
7.5	23.562	44.179	32.5	102.10	829.58	65.0	204.20	3318.31
8.0	25.133	50.266	33.0	103.67	855.30	66.0	207.34	3421.20
8.5	26.704	56.745	33.5	105.24	881.41	67.0	210.48	3525.66
9.0	28.274	63.617	34.0	106.81	907.92	68.0	213.63	3631.69
9.5	29.845	70.882	34.5	108.38	934.82	69.0	216.77	3739.29
10.0	31.416	78.540	35.0	109.96	962.11	70.0	219.91	3848.46
10.5	32.987	86.590	35.5	111.53	989.80	71.0	223.05	3959.20
11.0	34.558	95.033	36.0	113.10	1017.88	72.0	226.19	4071.51
11.5	36.128	103.87	36.5	114.67	1046.35	73.0	229.33	4185.39
12.0	37.699	113.10	37.0	116.24	1075.21	74.0	232.47	4300.85
12.5	39.270	122.72	37.5	117.81	1104.47	75.0	235.62	4417.87
13.0	40.841	132.73	38.0	119.38	1134.11	76.0	238.76	4536.47
13.5	42.412	143.14	38.5	120.95	1164.16	77.0	241.90	4656.63
14.0	43.982	153.94	39.0	122.52	1194.59	78.0	245.04	4778.37
14.5	45.553	165.13	39.5	124.09	1225.42	79.0	248.18	4901.68
15.0	47.124	176.72	40.0	125.66	1256.64	80.0	251.32	5026.56
15.5	48.695	188.69	40.5	127.23	1288.25	81.0	254.47	5153.01
16.0	50.265	201.06	41.0	128.81	1320.25	82.0	257.61	5281.03
16.5	51.836	213.83	41.5	130.38	1352.65	83.0	260.75	5410.62
17.0	53.407	226.98	42.0	131.95	1385.44	84.0	263.89	5541.78
17.5	54.978	240.53	42.5	133.52	1418.63	85.0	267.03	5674.50
18.0	56.549	254.47	43.0	135.09	1452.20	86.0	270.17	5808.81
18.5	58.119	268.80	43.5	136.66	1486.17	87.0	273.32	5944.69
19.0	59.690	283.53	44.0	138.23	1520.53	88.0	276.46	6082.13
19.5	61.261	298.65	44.5	139.80	1555.28	89.0	279.60	6221.13
20.0	62.832	314.16	45.0	141.37	1590.43	90.0	282.74	6361.74
20.5	64.403	320.06	45.5	142.94	1625.97	91.0	285.88	6503.89
21.0	65.973	346.36	46.0	144.51	1661.90	92.0	289.02	6647.62
21.5	67.544	363.05	46.5	146.08	1698.23	93.0	292.17	6792.92
22.0	69.115	380.13	47.0	147.65	1734.94	94.0	295.31	6939.78
22.5	70.686	397.61	47.5	149.23	1772.05	95.0	298.45	7088.23
23.0	72.257	415.48	48.0	150.80	1809.56	96.0	301.59	7238.24
23.5	73.827	433.74	48.5	152.37	1847.45	97.0	304.73	7389.83
24.0	75.398	452.39	49.0	153.94	1885.74	98.0	307.87	7542.98
24.5	76.969	471.44	49.5	155.51	1924.42	99.0	311.02	7697.68
25.0	78.540	490.87	50.0	157.08	1963.50	100.0	314.16	7854.00
25.5	80.111	510.71	51.0	160.22	2042.82			

Important Values of π.

	Log.		Log.
$\pi = 3.14159$	$0.4971499''$	$\sqrt[3]{\pi} = 1.46459$	$0.1657160''$
$\frac{1}{\pi^2} = 0.10132$	$\bar{1}.0056952''$	$\frac{1}{\pi} = 0.31831$	$\bar{1}.5028503''$
$\pi^2 = 9.8696$	$0.9942996''$	$\sqrt{\frac{1}{\pi}} = 0.54619$	$\bar{1}.7373437''$
$\sqrt{\pi} = 1.77245$	$0.2485749''$	$\frac{\pi}{4} = 0.785398$	$\bar{1}.8950899''$
$\pi^3 = 31.00628$	$1.4914496''$	$\frac{\pi}{6} = 0.52359$	$\bar{1}.7189986''$

Areas and Volumes of Bodies.

Volume of rectangular vessel $= abc$, where a, b and c are the three dimensions.
Area of triangle $= \frac{1}{2}$ base $\times$ height.

Area of circle $\frac{\pi}{4}d^2 = \pi r^2$. $r =$ radius. $\frac{\pi}{4} = 0.7851$.

Area of ellipse = transverse axis $\times$ .7854 $\times$ conjugate axis $= \pi ab$, where a and b are lengths of the two semi-axes.
Surface of sphere $= \pi d^2 = 4\pi r^2$. $d =$ diameter. $4\pi = 12.5664$.
Surface of cylinder = area of both ends $\times$ length $\times$ diameter.
Surface of cone = area of base + circumference of base $\times \frac{1}{2}$ slant height.

Volume of sphere $= \frac{4}{3}\pi r^3$. $\frac{4}{3}\pi = 4.1888 = d^3 \times 0.5236$, i.e., $\frac{\pi}{6}d^3$.
Volume of cylinder $= \pi r^2 h$. $r =$ radius of base. $h =$ height.
Volume of cone or pyramid = area of base $\times \frac{1}{3}$ perpendicular height.
Volume of frustum of cone $= 0.2618\ H(D^2 + d^2 + Dd)$, where D and d = diameters of each end, and H = perpendicular height.
Volume of cask considered as middle frustum of a prolate spheroid:

$$D = \sqrt{\frac{2B^2 + H^2}{3}}.$$

D = diameter of cylinder equal in volume and length to cask.
B = diameter at bung. H (or H') = diameter at head.

Or (approximately):
Ascertain the difference between B and H, and multiply it by .7 (or .68 if less than 6 inches); add the product to H to obtain diameter of required cylinder.
Or

$$\text{Capacity in gallons} = .0014162\ L(HH' + B^2).$$

L = length.
All the measurements are of course internal.

Physical.

To convert

Degrees of Twaddle's hydrometer into S.G. (water = 1000), multiply by 5, and add 1000.
S.G. (water = 1000) into degrees Twaddle, subtract 1000, and divide by 5.
S.G., air = 1 to S.G., $H = 1$, multiply by 14.438.
S.G., $H = 1$ to S.G., air = 1, multiply by 0.06926.

Weight in air to weight in vacuo:
P = weight required in vacuo.
q = weight in air.
V = volume of body weighed.
v = volume of the weights.
s = specific gravity of air (weight of one cubic unit).

$$P = q \times s(V - v).$$

TABLE SHOWING THE AREAS OF CIRCLES IN IMPERIAL GALLONS CORRESPONDING TO DIAMETERS IN IMPERIAL INCHES.

By the area in gallons is meant the number of gallons which are contained by a cylinder having the circle as base, and a height of one inch. This table can be employed for calculating the area of ellipses, according to the formula Area $= \frac{a+B-(a-B)}{2}$, where a is the area of the circle, having the transverse diameter of the ellipse as its diameter, B the area of corresponding circle for the congregate diameter, and $(a-B)$ the area of a circle having the difference between the transverse and congregate diameters as its diameter, the various diameters being expressed in inches.

Diam. in Ins.	0	1	2	3	4	5	6	7	8	9
1	.0028	.0034	.0040	.0047	.0055	.0063	.0072	.0081	.0091	.0102
2	.0113	.0124	.0137	.0149	.0163	.0177	.0191	.0206	.0222	.0238
3	.0254	.0272	.0290	.0308	.0327	.0346	.0367	.0387	.0409	.0430
4	.0453	.0476	.0499	.0523	.0548	.0573	.0599	.0625	.0652	.0680
5	.0708	.0736	.0765	.0795	.0825	.0856	.0888	.0920	.0952	.0986
6	.1019	.1053	.1088	.1124	.1160	.1196	.1233	.1271	.1309	.1348
7	.1387	.1427	.1468	.1509	.1551	.1593	.1036	.1679	.1723	.1767
8	.1812	.1858	.1904	.1951	.1998	.2046	.2094	.2143	.2193	.2243
9	.2294	.2345	.2397	.2449	.2502	.2556	.2610	.2665	.2720	.2776
10	.2832	.2889	.2947	.3005	.3063	.3122	.3182	.3243	.3303	.3365
11	.3427	.3490	.3553	.3616	.3681	.3746	.3811	.3877	.3944	.4011
12	.4078	.4147	.4215	.4285	.4355	.4425	.4496	.4568	.4640	.4713
13	.4787	.4860	.4935	.5010	.5086	.5162	.5239	.5316	.5394	.5472
14	.5551	.5631	.5711	.5792	.5873	.5955	.6037	.6120	.6204	.6288
15	.6373	.6458	.6544	.6630	.6717	.6805	.6893	.6982	.7071	.7161
16	.7251	.7342	.7433	.7525	.7618	.7711	.7805	.7899	.7994	.8090
17	.8186	.8282	.8379	.8477	.8575	.8674	.8774	.8874	.8974	.9075
18	.9177	.9279	.9382	.9485	.9589	.9694	.9799	.9905	1.0011	1.0118
19	1.0225	1.0333	1.0441	1.0551	1.0660	1.0770	1.0881	1.0992	1.1104	1.1217
20	1.1330	1.1443	1.1558	1.1672	1.1788	1.1903	1.2020	1.2137	1.2254	1.2372
21	1.2491	1.2610	1.2730	1.2851	1.2972	1.3093	1.3215	1.3338	1.3461	1.3585
22	1.3709	1.3834	1.3960	1.4086	1.4212	1.4339	1.4467	1.4595	1.4724	1.4854
23	1.4984	1.5114	1.5246	1.5377	1.5510	1.5642	1.5776	1.5910	1.6044	1.6179
24	1.6315	1.6451	1.5588	1.6726	1.6863	1 7002	1.7141	1.7281	1.7421	1.7562
25	1.7703	1.7845	1.7987	1.8131	1.8274	1.8418	1.8563	1.8708	1.8854	1.9001
26	1.9148	1.9295	1.9443	1.9592	1.9741	1.9891	2.0042	2.0193	2.0344	2.0496
27	2.0649	2.0802	2.0956	2.1110	2.1265	2.1421	2.1577	2.1734	2.1891	2.2049
28	2.2207	2.2366	2.2525	2.2685	2.2846	2.3007	2.3169	2.3331	2.3494	2.3657
29	2.3821	2.3986	2.4151	2.4317	2.4483	2.4650	2.4817	2.4985	2.5154	2.5323
30	2.5473	2.5663	2.5834	2.6005	2.6177	2.6349	2.6523	2.6696	2.6870	2.7045
31	2.7221	2.7396	2.7573	2.7750	2.7928	2.8106	2.8284	2.8464	2.8644	2.8824
32	2.9005	2.9187	2.9369	2.9551	2.9735	2.9019	3.0103	3.0288	3.0473	3.0660
33	3.0846	3.1033	3.1221	3.1410	3.1509	3.1788	3.1978	3.2169	3.2360	3.2552
34	3.2744	3.2937	3.3130	3.3324	3.3519	3.3714	3.3910	3.4106	3.4303	3.4500
35	3.4698	3.4897	3.5096	3.5296	3.5496	3.5697	3.5898	3.6100	3.6303	3.6506
36	3.6710	3.6914	3.7119	3.7324	3.7530	3.7736	3.7943	3.8151	3.8359	3.8568
37	3.8777	3.8987	3.9198	3.9109	3.9620	3.9833	4.0045	4.0259	4.0472	4.0687
38	4.0902	4.1117	4.1334	4.1550	4.1767	4.1985	4.2204	4.2423	4.2642	4.2862
39	4.3083	4.3304	4.3526	4.3748	4.3971	4.4195	4.4419	4.4643	4.4869	4.5094
40	4.5321	4.5548	4.5775	4.6003	4.6232	4.6461	4.6690	4.6921	4.7152	4.7383
41	4.7615	4.7848	4.8081	4.8314	4.8549	4.8783	4.9019	4.9255	4.9491	4.9728
42	4.9966	5.0204	5.0443	5.0682	5.0922	5.1163	5.1404	5.1645	5.1888	5.2130
43	5.2374	5.2618	5.2862	5.3107	5.3353	5.3599	5.3846	5.4093	5.4341	5.4589
44	5.4838	5.5088	5.5338	5.5588	5.5840	5.6091	5.6344	5.6597	5.6850	5.7104
45	5 7359	5.7614	5.7870	5.8126	5.8383	5.8641	5.8899	5.9157	5.9417	5.9676

AREAS OF CIRCLES IN IMPERIAL GALLONS FROM DIAMETERS—*Continued.*

Diam. in Ins.	0	1	2	3	4	5	6	7	8	9
46	5.9937	6.0198	6.0459	6.0721	6.0984	6.1247	6.1510	6.1775	6.2040	6.2305
47	6.2571	6.2838	6.3105	6.3372	6.3641	6.3909	6.4179	6.4449	6.4719	6.4990
48	6.5262	6.5534	6.5807	6.6080	6.6354	6.6629	6.6904	6.7179	6.7455	6.7732
49	6.8010	6.8287	6.8566	6.8845	6.9124	6.9405	6.9685	6.9967	7.0248	7.0531
50	7.0814	7.1097	7.1381	7.1666	7.1951	7.2237	7.2524	7.2810	7.3098	7.3386
51	7.3675	7.3964	7.4254	7.4544	7.4835	7.5126	7.5418	7.5711	7.6004	7.6298
52	7.6592	7.6887	7.7183	7.7479	7.7775	7.8072	7.8370	7.8668	7.8967	7.9266
53	7.9566	7.9867	8.0168	8.0470	8.0772	8.1075	8.1378	8 1682	8.1987	8.2292
54	8.2597	8.2903	8.3210	8.3518	8.3825	8.4134	8.4443	8.4753	8.5063	8.5373
55	8.5685	8.5997	8.6309	8.6622	8.6937	8.7250	8.7564	8.7880	8.8196	8.8512
56	8.8829	8.9146	8.9465	8.9783	9.0102	9.0422	9.0743	9.1064	9.1385	9.1707
57	9.2030	9.2353	9.2677	9.3001	9.3325	9.3651	9.3977	9.4303	9.4631	9.4959
58	9.5287	9.5616	9.5945	9.6275	9.6601	9.6937	9.7269	9.7601	9.7934	9.8267
59	9.8601	9.8933	9.9271	9.9607	9.9943	10.0280	10.0617	10.0993	10.1293	10.1632
60	10.1972	10.2312	10.2653	10.2994	10.3336	10.3679	10.4022	10.4365	10.4709	10.5054
61	10.5399	10 5745	10.6092	10.6439	10.6786	10.7134	10.7483	10.7832	10.8182	10.8533
62	10.8884	10.9235	10.9587	10.9940	11.0293	11.0647	11.1001	11.1356	11.1712	11.2068
63	11.2424	11.2781	11.3139	11.3497	11.3856	11.4216	11.4576	11.4936	11.5298	11.5659
64	11.6022	11.6384	11.6748	11.7112	11.7476	11.7842	11.8207	11.8573	11.8940	11.9308
65	11.9676	12.0044	12.0413	12.0783	12.1153	12.1524	12.1895	12.2267	12 2640	12.3013
66	12.3386	12.3760	12.4135	12.4511	12.4886	12.5263	12.5640	12.6017	12.6396	12.6774
67	12.7154	12.7533	12.7914	12.8295	12.8676	12.9058	12.9441	12.9824	13.0203	13.0593
68	13.0978	13.1363	13.1749	13.2136	13.2523	13.2911	13.3299	13.3688	13.4078	13.4468
69	13.4858	13.5249	13.5641	13.6033	13.6420	13.6820	13.7214	13.7608	13.8003	13 8399
70	13.8795	13.9192	13.9590	13.9938	14.0386	14.0785	14.1185	14.1585	14.1986	14.2387
71	14.2789	14.3192	14.3595	14.3999	14.4403	14.4808	14.5213	14.5619	14.6025	14.6433
72	14.6840	14.7248	14.7657	14.8036	14.8476	14.8886	14.9297	14.9709	15.0121	15.0534
73	15.0947	15.1361	15.1775	15.2190	15.2606	15.3022	15.3439	15.3856	15.4274	15.4692
74	15.5111	15.5531	15.5951	15.6371	15.6792	15.7214	15.7637	15.8059	15.8483	15.8907
75	15.9332	15.9757	15.0182	16.0609	16.1036	16.1463	16.1891	16.2320	16.2749	16.3179
76	16.3609	16.4040	16.4471	16.4903	16.5336	16.5769	16.6202	16.6637	16.7071	16.7507
77	16.7943	16.8379	16.8816	16.9254	16.9692	17.0131	17.0570	17.1010	17.1450	17.1891
78	17.2333	17.2775	17.3218	17.3661	17.4105	17.4550	17.4995	17.5440	17.5886	17.6333
79	17.6780	17.7228	17.7676	17.8125	17.8575	17.9025	17.9476	17.9927	18.0379	18.0831
80	18.1284	18.1738	18.2192	18.2646	18.3101	18.3557	18.4013	18.4470	18.4928	18.5386
81	18.5844	18.6304	18.6763	18.7224	18.7684	18.8146	18.8608	18.9079	18.9534	18.9997
82	19.0462	19.0926	19.1392	19.1858	19.2324	19.2791	19.3259	19.3727	19.4193	19.4665
83	19.5135	19.5603	19.6077	19.6548	19.7021	19.7493	19.7967	19.8441	19.8915	19.9390
84	19.9866	20.0342	20.0819	20.1296	20.1774	20.2252	20.2731	20.3211	20.3691	20.4171
85	20.4653	20.5135	20.5617	20.6100	20.6583	20.7067	20.7552	20.8037	20.8523	20.9096
86	20.9496	20.9934	21.0472	21.0961	21.1450	21.1940	21.2430	21.2921	21.3412	21.3904
87	21.4397	21.4890	21.5384	21.5878	21.6373	21.6868	21.7364	21.7861	21.8358	21.8856
88	21.9354	21.9853	21 0352	22.0852	22.1352	22.1854	22.2355	22.2857	22.3360	22.3863
89	22.4367	22.4872	22.5377	22.5883	22.6389	22.6895	22.7403	22.7911	22.8419	22.8928
90	22.9438	22.9948	23.0459	23.0970	23.1482	23.1994	23.2507	23.3021	23.3535	23.4049
91	23.4565	23.5080	23.5597	23.6114	23.6631	23.7149	23.7668	23.8187	23.8707	23.9227
92	23.9748	24.0270	24.0792	24.1314	24.1838	24.2361	24.2886	24.3411	24.3956	24.4462
93	24.4939	24.5516	24.6048	24.6572	24.7100	24.7630	24.8160	24.8690	24.9222	24.9753
94	25.0285	25.0818	25.1352	25.1886	25.2420	25.2955	25.3491	25.4027	25.4564	25.5101
95	25.5639	25.6177	25.6717	25 7256	25.7796	25.8337	25.8878	25.9420	25.9963	25.0506
96	26.1049	26.1593	26.2139	26.2683	26.3229	26.3776	26.4323	26.4870	26.5418	26.5967
97	26.6516	26.7066	26.7616	26.8167	26.8719	26.9271	26.9823	27.0377	27.0930	27.1485
98	27.2040	27.2595	27.3151	27.3708	27.4265	27.4823	27.5381	27.5940	27.6499	27.7059
99	27.7620	27.8181	27.8743	27.9305	27.9868	28.0431	28.0995	28.1560	28.2125	28.2690
100	28.3257	28.3823	28.4391	28.4959	28.5527	28.6096	28.6666	28.7236	28.7807	28.8378

AREAS OF CIRCLES IN IMPERIAL GALLONS FROM DIAMETERS—*Continued.*

Diam. in Ins.	0	1	2	3	4	5	6	7	8	9
101	28.8950	28.9522	29.0096	29.0669	29.1243	29.1818	29.2393	29.2969	29.3546	29.4123
102	29.4700	29.5278	29.5857	20.6436	29.7016	29.7596	29.8177	29.8759	29.9341	29.9924
103	30.0507	30.1091	30.1675	30.2260	30.2845	30.3432	30.4018	30.4605	30.5193	30.5781
104	30.6370	30.6960	30.7550	30.8140	30.8732	30.9323	30.9916	31.0508	31.1102	31.1696
105	31.2290	31.2886	31.3481	31.4077	31.4674	31.5272	31.5870	31.6468	31.7067	31.7667
106	31.8267	31.8868	31.9469	32.0071	32.0674	32.1277	32.1880	32.2485	32.3089	32.3695
107	32.4301	32.4907	32.5514	32.6122	32.6730	32.7338	32.7948	32.8558	32.9168	32.9779
108	33.0391	33.1003	33.1615	33.2229	33.2842	33.3457	33.4072	33.4687	33.5303	33.5920
109	33.6537	33.7155	33.7773	33.8392	33.9012	33.9632	34.0252	34.0874	34.1495	34.2118
110	34.2741	34.3364	34.3988	34.4613	34.5238	34.5863	34.6490	34.7117	34.7744	34.8372
111	34.9001	34.9630	35.0259	35.0890	35.1520	35.2152	35.2784	35.3416	35.4049	35.4683
112	35.5317	35.5952	35.6587	35.7223	35.7860	35.8497	35.9134	35.9772	36.0411	36.1051
113	36.1690	36.2331	36.2972	36.3613	36.4256	36.4898	36.5542	36.6185	36.6830	36.7475
114	36.8120	36.8766	36.9413	37.0060	37.0708	37.1357	37.2006	37.2655	37.3305	27.3956
115	37.4607	37.5259	37.5911	37.6564	37.7217	37.7871	37.8526	37.9181	37.9837	38.0493
116	38.1150	38.1808	38.2466	38.3124	38.3783	38.4443	38.5103	38.5764	38.6426	38.7088
117	38.7750	38.8413	38.9077	38.9741	39.0406	39.1071	39.1737	39.2404	39.3071	39.3738
118	39.4407	39.5075	39.5745	39.6415	39.7085	39.7756	39.8428	39.9100	39.9773	40.0446
119	40.1120	40.1791	40.2469	40.3145	40.3821	40.4498	40.5175	40.5853	40.6531	40.7210
120	40.7890	40.8570	40.9250	40.9932	41.0613	41.1296	41.1979	41.2662	41.3346	41.4031
121	41.4716	41.5402	41.6088	41.6775	41.7463	41.8151	41.8839	41.9528	42.0218	42.0908
122	42.1599	42.2291	42.2983	42.3675	42.4368	42.5062	42.5756	42.6451	42.7147	42.7843
123	42.8539	42.9236	42.9934	43.0632	43.1331	43.2030	43.2730	43.3431	43.4132	43.4833
124	43.5536	43.6239	42.6942	43.7646	43.8350	43.9055	43.9761	44.0467	44.1173	44.1881
125	44.2589	44.3297	44.4006	44.4716	44.5426	44.6136	44.6848	44.7560	44.8272	44.8985
126	44.9698	45.0412	45.1127	45.1842	45.2558	45.3275	45.3991	45.4709	45.5427	45.6146
127	45.6865	45.7585	45.8305	45.9026	45.9747	46.0469	46.1192	46.1915	46.2639	46.3363
128	46.4088	46.4813	46.5539	46.6266	46.6993	46.7721	46.8449	46.9178	46.9907	47.0637
129	47.1368	47.2099	47.2830	47.3563	47.4295	47.5029	47.5763	47.6497	47.7232	47.7968
130	47.8704	47.9441	48.0178	48.0916	48.1654	48.2392	48.3133	48.3873	48.4611	48.5355
131	48.6097	48.6839	48.7582	48.8326	48.9070	48.9815	49.0560	49.1306	49.2052	49.2799
132	49.3547	49.4295	49.5043	49.5793	49.6542	49.7293	49.8014	49.8795	49.9547	50.0300
133	50.1053	50.1807	50.2561	50.3316	50.4071	50.4827	50.5584	50.6341	50.7099	50.7857
134	50.8616	50.9375	50.0135	51.0896	51.1657	51.2419	51.3181	51.3944	51.4707	51.5471
135	51.6235	51.7001	51.7766	51.8532	51.9299	52.0067	52.0834	52.1603	52.2372	52.3142
136	52.3912	52.4682	52.5454	52.6226	52.6998	52.7771	52.8545	52.9319	53.0094	53.0869
137	53.1645	53.2421	53.3198	53.3976	53.4754	53.5532	53.6312	53.7091	53.7872	53.8653
138	53.9434	54.0216	54.0999	54.1782	54.2566	54.3350	54.4135	54.4921	54,5707	54.6493
139	54.7280	54.8068	54.8856	54.9645	54.0435	55.1225	55.2015	55.2807	55.3598	55.4390
140	55.5183	55.5977	55.6771	55.7565	55.8360	55.9156	55.9952	56.0749	56.1546	56.2344
141	56.3143	56.3942	56.4742	56.5542	56.6343	56.7144	56.7946	56.8748	56.9551	57.0355
142	57.1159	57.1964	57.2769	57.3575	57.4381	57.5188	57.5996	57.6804	57.7613	57.8422
143	57.9232	58.0042	58.0853	58.1665	58.2477	58.3290	58.4103	58.4917	58.5731	58.6546
144	58.7261	58.8177	58.8994	58.9811	58.0629	59.1447	59.2266	59.3086	59.3906	59.4726
145	59.5547	59.6369	59.7191	59.8014	59.8838	59.9662	60.0486	60.1311	60.2137	60.2963
146	60.3790	60.4618	60.5446	60.6274	60.7103	60.7933	60.8762	60.9594	60.0425	61.1257
147	61.2090	61.2923	61.3756	61.4591	61.5425	61.6261	61.7097	61.7933	61.8770	61.9608
148	62.0446	62.1284	62.2124	62.2964	62.3804	62.4615	62.5487	62.6329	62.7171	62.8015
149	62.8858	62.9703	63.0548	63.1393	63.2239	63.3086	63.3933	63.4781	63.5629	63.6478
150	63.7328	63.8178	63.9029	63.9880	64.0731	64.1584	64.2437	64.3290	64.4144	64.4999
151	64.5854	64.0710	64.7566	64.8423	64.9280	65.0138	65.0997	65.1856	65.2716	65.3576
152	65.4437	65.5298	65.6160	65.7022	65.7886	65.8749	65.9613	65.0478	66.1344	66.2209
153	66.3076	66.3943	66.4811	66.5679	66.6548	66.7417	66.8287	66.9157	67.0028	67.0900
154	67.1772	67.2645	67.3518	67.4392	67.5266	67.6141	67.7017	67.7893	67.8770	67.9617
155	68.0525	68.1403	68.2282	68.3161	68.4041	68.4922	68.5803	68.6685	68.7567	68.8450

AREAS OF CIRCLES IN IMPERIAL GALLONS FROM DIAMETERS—*Continued.*

Diam. in Ins	0	1	2	3	4	5	6	7	8	9
156	68.9334	69.0219	69.1103	69.1988	69.2873	69.3760	69.4647	69.5534	69.6422	69.7311
157	69.8200	69.9090	69.9980	70.0871	70.1762	70.2654	70.3547	70.4440	70.5333	70.6228
158	70.7122	70.8018	70.8914	70.9810	71.0707	71.1605	71.2503	71.3402	71.4301	71.5201
159	71.6102	71.7003	71.7904	71.8806	71.9709	72.0613	72.1516	72.2421	72.3326	72.4231
160	72.5138	72.6044	72.6952	72.7859	72.8768	72.9677	73.0586	73.1496	73.2407	73.3318
161	73.4230	73.5142	73.6055	73.6969	73.7883	73.8798	73.9713	74.0629	74.1545	74.2462
162	74.3379	74.4297	74.5216	74.6135	74.7055	74.7975	74.8896	74.9817	75.0739	75.1662
163	75.2585	75.3509	75.4433	75.5358	75.6283	75.7209	75.8136	75.9063	75.9991	76.0919
164	76.1848	76.2777	76.3707	76.4637	76.5569	76.6500	76.7432	76.8365	76.9298	77.0232
165	77.1167	77.2102	77.3037	77.3974	77.4910	77.5848	77.6786	77.7724	77.8663	77.9603
166	78.0543	78.1483	78.2425	78.3366	78.4309	78.5252	78.6195	78.7139	78.8084	78.9029
167	78.9975	79.0921	79.1868	79.2816	79.3764	79.4713	79.5662	79.6612	79.7562	79.8513
168	79.9464	80.0416	80.1369	80.2322	80.3276	80.4230	80.5185	80.6140	80.7096	80.8053
169	80.9010	80.9968	81.0926	81.1885	81.2844	81.3804	81.4765	81.5726	81.6687	81.7650
170	81.8612	81.9576	82.0540	82.1504	82.2469	82.3435	82.4401	82.5368	82.6335	82.7303
171	82.8271	82.9240	83.0210	83.1180	83.2151	83.3122	83.4094	83.5067	83.6039	83.7013
172	83.7987	83.8962	83.9937	84.0913	84.1889	84.2866	84.3844	84.4822	84.5801	84.6780
173	84.7760	84.8740	84.9721	85.0702	85.1684	85.2667	85.3650	85.4634	85.5618	85.6603
174	85.7589	85.8575	85.9561	86.0548	86.1536	86.2524	86.3513	86.4503	86.5493	86.6483
175	86.7474	86.8466	86.9458	87.0451	87.1444	87.2438	87.3433	87.4428	87.5424	87.6420
176	87.7417	87.8414	87.9412	88.0410	88.1409	88.2409	88.3409	88.4410	88.5411	88.6413
177	88.7416	88.8419	88.9422	89.0426	89.1431	89.2436	89.3442	89.4449	89.5455	89.6463
178	89.7471	89.8480	89.9489	90.0499	90.1509	90.2520	90.3532	90.4544	90.5556	90.6570
179	90.7583	90.8598	90.9613	91.0628	91.1644	91.2661	91.3678	91.4696	91.5714	91.6733
180	91.7752	91.8772	91.9793	92.0814	92.1836	92.2858	92.3881	92.4904	92.5928	92.6953
181	92.7978	92.9004	93.0030	93.1057	93.2084	93.3112	93.4140	93.5170	93.6199	93.7229
182	93.8260	93.9292	94.0323	94.1356	94.2389	94.3423	94.4457	94.5491	94.6527	94.7563
183	94.8599	94.9636	95.0674	95.1712	95.2750	95.3790	95.4830	95.5870	95.6911	95.7952
184	95.8995	96.0037	96.1080	96.2124	96.3169	96.4214	96.5259	96.6305	96.7352	96.8399
185	96.9447	97.0495	97.1544	97.2593	97.3644	97.4694	97.5745	97.6797	97.7849	97.8902
186	97.9956	98.1010	98.2064	98.3119	98.4175	98.5231	98.6288	98.7345	98.8403	98.9462
187	99.0521	99.1581	99.2641	99.3702	99.4763	99.5825	99.6888	99.7951	99.9014	100.0078
188	100.1143	100.2209	100.3274	100.4341	100.5403	100.6476	100.7544	100.8612	100.9682	101.0752
189	101.1822	101.2893	101.3965	101.5037	101.6109	101.7183	101.8256	101.9331	102.0406	102.1481
190	102.2557	102.3634	102.4711	102.5789	102.6868	102.7946	102.9026	103.0106	103.1187	103.2268
191	103.3350	103.4432	103.5515	103.6598	103.7682	103.8767	103.9852	104.0938	104.2024	104.3111
192	104.4198	104.5286	104.6375	104.7464	104.8554	104.9644	105.0735	105.1826	105.2918	105.4011
193	105.5104	105.6197	105.7292	105.8386	105.9482	106.0578	106.1674	106.2771	106.3869	106.4967
194	106.6066	106.7165	106.8265	106.9365	107.0466	107.1568	107.2670	107.3773	107.4876	107.5980
195	107.7084	107.8189	107.9294	108.0401	108.1508	108.2615	108.3723	108.4831	108.5940	108.7050
196	108.8160	108.9270	109.0382	109.1493	109.2606	109.3719	109.4832	109.5946	109.7061	109.8176
197	109.9292	110.0408	110.1525	110.2642	110.3760	110.4879	110.5998	110.7118	110.8238	110.9359
198	111.0480	111.1602	111.2725	111.3848	111.4972	111.6096	111.7221	111.8346	111.9472	112.0599
199	112.1726	112.2853	112.3982	112.5110	112.6240	112.7370	112.8500	112.9631	113.0763	113.1895
200	113.3028	113.4161	113.5295	113.6429	113.7564	113.8700	113.9836	114.0973	114.2110	114.3248

TABLE SHOWING THE AREAS OF SEMI-SQUARES IN IMPERIAL GALLONS CORRESPONDING TO SIDES IN IMPERIAL INCHES.

This table shows the number of gallons contained in a prism having the semi-square described on the side as base, and a height of one inch. It is of use in finding the area in gallons of a rectangle. The area is $a \times b$, a and b being the sides of the rectangle. But

$$ab = \frac{a^2}{2} + \frac{b^2}{2} - \frac{(a-b)^2}{2}.$$

Rules.—Add the area of the semi-square on the longer side of the rectangle to the area of the semi-square on the shorter side, and from the sum deduct the semi-square on a line equal to the difference between the two sides, dimensions being in inches.

Sides in Ins.	0	1 .00002	2 .00007	3 .00016	4 .00029	5 .00045	6 .00065	7 .00088	8 .00115	9 .00146
1	.0018	.0022	.0026	.0030	.0035	.0041	.0046	.0052	.0058	.0065
2	.0072	.0080	.0087	.0095	.0101	.0113	.0122	.0131	.0141	.0152
3	.0162	.0173	.0185	.0196	.0208	.0221	.0234	.0247	.0260	.0274
4	.0289	.0303	.0318	.0333	.0349	.0365	.0282	.0398	.0415	.0433
5	.0451	.0469	.0488	.0507	.0526	.0545	.0566	.0586	.0607	.0628
6	.0649	.0671	.0693	.0716	.7390	.0762	.0786	.0809	.0834	.0859
7	.0884	.0609	.0935	.0961	.0987	.1014	.1042	.1069	.1097	.1125
8	.1154	.1183	.1213	.1242	.1272	.1303	.1334	.1265	.1396	.1428
9	.1461	.1493	.1526	.1560	.1593	.1627	.1662	.1697	.1732	.1767
10	.1803	.1840	.1876	.1913	.1950	.1988	.2026	.2065	.2103	.2142
11	.2182	.2222	.2262	.2303	.2344	.2385	.2426	.2468	.2511	.2554
12	.2597	.2640	.2684	.2728	.2773	.2818	.2863	.2908	.2954	.3001
13	.3048	.3095	.3142	.3190	.3238	.3286	.3335	.3385	.3434	.3484
14	.3534	.3585	.3636	.3688	.3739	.3791	.3844	.3897	.3950	.4003
15	.4057	.4112	.4166	.4221	.4277	.4332	.4388	.4445	.4502	.4559
16	.4616	.4674	.4733	.4791	.4850	.4909	.4969	.5029	.5090	.5150
17	.5211	.5273	.5335	.5397	.5460	.5523	.5586	.5649	.5713	.5778
18	.5843	.5908	.5973	.6039	.6105	.6172	.6239	.6306	.6373	.6441
19	.6510	.6579	.6648	.6717	.6787	.6857	.6927	.6998	.7070	.7141
20	.7213	.7285	.7358	.7431	.7504	.7578	.7652	.7727	.7802	.7877
21	.7952	.8028	.8105	.8181	.8258	.8336	.8413	.8491	.8570	.8649
22	.8728	.8807	.8887	.8967	.9048	.9129	.9210	.9292	.9374	.9457
23	.9539	.9622	.9706	.9790	.9874	.9959	1.0043	1.0129	1.0214	1.0300
24	1.0387	1.0474	1.0561	1.0648	1.0736	1.0824	1.0913	1.1002	1.1091	1.1180
25	1.1270	1.1361	1.1451	1.1543	1.1634	1.1726	1.1818	1.1910	1.2003	1.2097
26	1.2190	1.2284	1.2378	1.2473	1.2568	1.2663	1.2759	1.2855	1.2952	1.3049
27	1.3146	1.3243	1.3341	1.3440	1.3538	1.3637	1.3737	1.3836	1.3936	1.4037
28	1.4138	1.4239	1.4340	1.4442	1.4544	1.4647	1.4750	1.4853	1.4957	1.5061
29	1.5166	1.5270	1.5375	1.5481	1.5587	1.5693	1.5800	1.5906	1.6014	1.6121
30	1.6229	1.6338	1.6447	1.6556	1.6665	1.6775	1.6885	1.6996	1.7107	1.7218
31	1.7329	1.7441	1.7554	1.7666	1.7780	1.7893	1.8007	1.8121	1.8235	1.8350
32	1.8465	1.8581	1.8697	1.8813	1.8930	1.9047	1.9164	1.9282	1.9400	1.9519
33	1.9638	1.9757	1.9876	1.9996	2.0117	2.0237	2.0358	2.0480	2.0601	2.0723
34	2.0846	2.0969	2.1092	2.1215	2.1339	2.1463	2.1588	2.1713	2.1838	2.1964
35	2.2090	2.2216	2.2343	2.2470	2.2598	2.2726	2.2854	2.2983	2.3111	2.3241
36	2.3370	2.3500	2.3631	2.3762	2.3893	2.4024	2.4156	2.4288	2.4421	2.4554
37	2.4687	2.4820	2.4954	2.5089	2.5223	2.5358	2.5494	2.5630	2.5766	2.5902
38	2.6039	2.6176	2.6314	2.6452	2.6590	2.6729	2.6868	2.7007	2.7147	2.7287
39	2.7428	2.7569	2.7710	2.7851	2.7093	2.8136	2.8278	2.8121	2.8565	2.8708
40	2.8852	2.8997	2.9142	2.9287	2.9432	2.9578	2.9724	2.9871	3.0018	3.0165
41	3.0313	3.0461	3.0609	3.0758	3.0907	3.1057	3.1207	3.1357	3.1507	3.1658
42	3.1810	3.1961	3.2113	3.2266	3.2418	3.2572	3.2725	3.2879	3.3033	3.3188
43	3.3342	3.3498	3.3653	3.3809	3.3966	3.4122	3.4279	3.4437	3.4595	3.4753
44	3.4911	3.5070	3.5229	3.5389	3.5549	3.5709	3.5870	3.6031	3.6192	3.6354
45	3.6516	3.6679	3.6842	3.7005	3.7168	3.7332	3.7496	3.7661	3.7826	3.7991

AREAS OF SEMI-SQUARES IN IMPERIAL GALLONS—*Continued.*

Sides in Ins.	0	1	2	3	4	5	6	7	8	9
46	3.8157	3.8323	3.8490	3.8657	3.8824	3.8991	3.9159	3.9327	3.9496	3.9665
47	3.9834	.40004	4.0174	4.0344	4.0515	4.0686	4.0858	4.1030	4.1202	4.1374
48	4.1547	4.1721	4.1894	4.2068	4.2243	4.2417	4.2593	4.2768	4.2944	4.3120
49	4.3297	4.3473	4.3651	4.3828	4.4006	4.4185	4.4363	4.4542	4.4722	4.4902
50	4.5082	4.5262	4.5443	4.5624	4.5806	4.5988	4.6170	4.6353	4.6536	4.6719
51	4.6903	4.7087	4.7272	4.7456	2.7642	4.7827	4.8013	4.8199	4.8386	4.8573
52	4.8760	4.8948	4.9136	4.9325	4.9513	4.9703	4.9892	5.0082	5.0272	5.0463
53	5.0651	5.0845	5.1037	5.1229	5.1421	5.1614	5.1807	5.2001	5.2195	5.2389
54	5.2583	5.2778	5.2974	5.3169	5.3365	5.3562	5.3758	5.3955	5.4153	5.4351
55	5.4549	5.4747	5.4946	5.5146	5.5345	5.5545	5.5746	5.5940	5.6147	5.6349
56	5.6551	5.6753	5.6955	5.7158	5.7361	5.7565	5.7769	5.7973	5.8178	5.8383
57	5.8588	5.8794	5.9000	5.9207	5.9413	5.9621	5.9828	6.0036	6.0244	6.0453
58	6.0662	6.0871	6.1081	6.1291	6.1502	6.1712	6.1924	6.2135	6.2347	6.2559
59	6.2772	6.2985	6.3198	6.3412	6.3626	6.3840	6.4055	6.4270	6.4486	6.4702
60	6.4918	6.5134	6.5351	6.5569	6.5786	6.6004	6.6223	6.6441	6.6660	6.6880
61	6.7100	6.7320	6.7540	6.7761	6.7983	6.8204	6.8426	6.8649	6.8871	6.9094
62	6.9318	6.9512	6.9766	6.9990	7.0215	7.0440	7.0666	7.0892	7.1118	7.1345
63	7.1572	7.1799	7.2027	7.2255	7.2484	7.2712	7.2942	7.3171	7.3401	7.3631
64	7.3862	7.4003	7.4324	7.4556	7.4788	7.5021	7.5253	7.5487	7.5720	7.5954
65	7.6188	7.6423	6.6658	7.6893	7.7129	7.7265	7.7601	7.7838	7.8075	7.8313
66	7.8550	7.8789	7.9027	7.9266	7.9505	7.9745	7.9985	8.0226	8.0466	8.0707
67	8.0949	8.1191	8.1433	8.1675	8.1918	8.2162	8.2405	8.2649	8.2893	8.3138
68	8.3383	8.3629	8.3874	8.4121	8.4367	8.4614	8.4861	8.5109	8.5357	8.5605
69	8.5854	8.6103	8.6352	8.6602	8.6852	8.7102	8.7353	8.7604	8.7856	8.8108
70	8.8360	8.8613	8.8866	8.9119	8.9373	8.9627	8.9881	9.0136	9.0391	9.0647
71	9.0903	9.1159	9.1416	9.1673	9.1930	9.2188	9.2446	9.2704	9.2963	9.3222
72	9.3482	9.3741	9.4002	9.4262	9.4523	9.4784	9.5046	9.5308	9.5570	9.5833
73	9.6096	9.6360	9.6624	9.6888	9.7152	9.7417	9.7682	9.7948	9.8214	9.8480
74	9.8747	9.9014	9.9282	9.9549	9.9818	10.0086	10.0355	10.0624	10.0894	10.1164
75	10.1434	10.1705	10.1976	10.2247	10.2519	10.2791	10.3063	10.3336	10.3609	10.3883
76	10.4157	10.4431	10.4706	10.4981	10.5256	10.5532	10.5808	10.6084	10.6361	10.6638
77	10.6916	10.7191	10.7472	10.7751	10.8030	10.8309	10.8589	10.8869	10.9149	10.9430
78	10.9711	10.9992	11.0274	11.0557	11.0839	11.1122	11.1405	11.1689	11.1973	11.2257
79	11.2542	11.2827	11.3113	11.3398	11.3685	11.3971	11.4258	11.4545	11.4833	11.5121
80	11.5409	11.5698	11.5987	11.6276	11.6566	11.6856	11.7147	11.7438	11.7729	11.8021
81	11.8313	11.8605	11.8898	11.9191	11.9484	11.9778	12.0072	12.0366	12.0661	12.0956
82	12.1252	12.1548	12.1844	12.2141	12.2438	12.2735	12.3083	12.3331	12.3629	12.3928
83	12.4227	12.4527	12.4827	12.5127	12.5428	12.5729	12.6030	12.6332	12.6634	12.6936
84	12.7239	12.7542	12.7845	12.8149	12.8453	12.8758	12.0063	12.9368	12.9674	12.9980
85	13.0286	13.0593	13.0900	13.1208	13.1515	13.1824	13.2132	13.2441	13.2750	13.3060
86	13.3370	13.3680	13.3991	13.4302	13.4613	13.4925	13.5237	13.5550	13.5863	12.6176
87	13.6490	13.6803	13.7118	13.7432	13.7747	13.8063	13.8379	13.8695	13.9011	13.9328
88	13.9645	13.9963	14.0281	14.0599	14.0918	14.1237	14.1556	14.1870	14.2196	14.2516
89	14.2837	14.3158	14.3480	14.3802	14.4124	14.4446	14.4769	14.5093	14.5416	14.5740
90	14.6065	14.6390	14.6715	14.7040	14.7366	14.7692	14.8019	14.8346	14.8673	14.9001
91	14.9329	14.9657	14.9986	15.0315	15.0644	15.0974	15.1304	15.1635	15.1966	15.2297
92	15.2629	15.2961	15.3293	15.3626	15.3959	15.4292	15.4626	15.4960	15.5295	15.5630
93	15.5965	15.6300	15.6636	15.6973	15.7309	15.7646	15.7984	15.8322	15.8660	15.8998
94	15.9337	15.9676	16.0016	16.0356	16.0696	16.1037	16.1378	16.1719	16.2061	16.2403
95	16.2745	16.3088	16.3431	16.3775	16.4119	16.4463	16.4807	16.5152	16.5498	16.5843
96	16.6189	16.6536	16.6883	16.7230	16.7577	16.7925	16.8273	16.8622	16.8971	16.9320
97	16.9670	17.0020	17.0370	17.0721	17.1072	17.1423	17.1775	17.2127	17.2480	17.2833
98	17.3186	17.3540	17.3894	17.4248	17.4603	17.4958	17.5313	17.5669	17.6025	17.6382
99	17.6739	17.7096	17.7453	17.7811	17.8170	17.8528	17.8887	17.9247	17.9606	17.9967
100	18.0327	18.0688	18.1049	18.1411	18.1773	18.2135	18.2497	18.2860	18.3224	18.3588

AREAS OF SEMI-SQUARES IN IMPERIAL GALLONS—*Continued.*

Sides in Ins.	0	1	2	3	4	5	6	7	8	9
101	18.3952	18.4316	18.4681	18.5046	18.5412	18.5777	18.6144	18.6510	18.6877	18.7245
102	18.7612	18.7980	18.8349	18.8717	18.9087	18.9456	18.9826	19.0196	19.0567	19.0938
103	19.1309	19.1681	19.2053	19.2425	19.2798	19.3171	19.3544	19.3918	19.4292	19.4667
104	19.5042	19.5417	19.5793	19.6169	19.6545	19.6922	19.7299	19.7676	19.8054	19.8432
105	19.8811	19.9189	19.9569	19.9948	20.0328	20.0709	20.1089	20.1470	20.1852	20.2233
106	20.2615	20.2998	20.3381	20.3764	20.4148	20.4531	20.4916	20.5300	20.5685	20.6071
107	20.6456	20.6843	20.7229	20.7616	20.8003	20.8390	20.8778	20.9167	20.9555	20.9944
108	21.0333	21.0723	21.1113	21.1504	21.1894	21.2286	21.2677	21.3060	21.3461	21.3 54
109	21.4247	21.4640	21.5034	21.5428	21.5822	21.6217	21.6612	21.7007	21.7403	21.7799
110	21.8196	21.8593	21.8990	21.9388	21.9785	22.0184	22.0583	22.0982	22.1381	22.1781
111	22.2181	22.2581	22.2982	22.3384	22.3785	22.4187	22.4589	22.4993	22.5395	22.5793
112	22.6202	22.6606	22.7011	22.7416	22.7821	22.8226	22.8632	22.9039	22.9445	22.9852
113	23.0260	23.0667	23.1075	23.1484	23.1893	23.2302	23.2711	23.3121	23.3531	23.3942
114	23.4353	23.4764	23.5176	23.5588	23.6000	23.6413	23.6826	23.7240	23.7654	23.8068
115	23.8483	23.8897	23.9313	23.9728	24.0144	24.0561	24.0978	24.1395	24.1812	24.2230
116	24.2648	24.3067	24.3486	24.3905	24.4324	24.4744	24.5165	24.5585	24.6006	24.6428
117	24.6850	24.7272	24.7694	24.8117	24.8540	24.8964	24.9388	24.9812	25.0237	25.0662
118	25.1087	25.1513	25.1939	25.2366	25.2793	25.3220	25.3647	25.4075	25.4503	25.4932
119	25.5361	25.5790	25.6220	25.6650	25.7081	25.7512	25.7943	25.8374	25.8806	25.9238
120	25.9671	26.0104	26.0537	26.0971	26.1405	26.1839	26.2274	26.2709	26.3145	26.3581
121	26.4017	26.4453	26.4890	26.5328	26.5765	26.6203	26.6642	26.7080	26.7519	26.7959
122	26.8399	26.8839	26.9279	26.9720	27.0162	27.0603	27.1045	27.1488	27.1930	27.2373
123	27.2817	27.3261	27.3705	27.4149	27.4594	27.5039	27.5485	27.5931	27.6377	27.6824
124	27.7271	27.7718	27.8166	27.8614	27.9063	27.9511	27.9961	28.0410	28.0860	28.1310
125	28.1761	28.2212	28.2663	28.3115	28.3567	28.4020	28.4472	28.4920	28.5379	28.5833
126	28.6287	28.6742	28.7197	28.7652	28.8108	28.8564	28.9020	28.9477	28.9934	28.0392
127	29.0849	29.1308	29.1766	29.2225	29.2684	29.3144	29.3604	29.4065	29.4525	29.4986
128	29.5448	29.5910	29.6372	29.6831	29.7297	29.7761	29.8224	29.8688	29.9152	29.9617
129	30.0082	30.0548	30.1013	30.1480	30.1946	30.2413	30.2880	30.3349	30.3816	30.4284
130	30.4753	30.5222	30.5691	30.6161	30.6631	30.7101	30.7572	30.8043	30.8515	30.8987
131	30.9459	30.9932	31.0405	31.0878	31.1352	31.1820	31.2300	31.2775	31.3250	31.3726
132	31.4202	31.4678	31.5155	31.5632	31.6109	31.6587	31.7065	31.7543	31.8022	31.8501
133	31.8981	31.9460	31.9941	32.0421	32.0902	32.1383	32.1865	32.2347	32.2829	32.3312
134	32.3795	32.4279	32.4763	32.5247	32.5731	32.6216	32.6701	32.7187	32.7673	32.8159
135	32.8646	32.9133	32.9621	33.0108	33.0596	33.1085	33.1574	33.2063	33.2553	33.3043
136	33.3533	33.4024	33.4515	33.5006	33.5498	33.5990	33.6482	33.6975	33.7468	33.7962
137	33.8456	33.8950	33.9445	33.9940	34.0435	34.0931	31.1427	34.1923	34.2420	34.2017
138	34.3415	34.3913	34.4411	34.4910	35.5409	34.5908	34.6408	34.6908	34.7408	34.7909
139	34.8410	34.8911	34.9413	34.9915	35.0418	35.0921	35.1424	35.1928	35.2432	35.2936
140	35.3441	35.3946	35.4452	35.4957	35.5461	35.5970	35.6477	35.6984	35.7492	35.8000
141	35.8508	35.9017	35.9526	36.0035	36.0545	36.1055	33.1566	36.2077	36.2588	36.3099
142	36.3611	36.4124	36.4636	36.5149	36.5663	36.6177	36.6691	36.7205	36.7720	36.8235
143	36.8751	36.9267	36.9783	37.0300	37.0817	37.1334	37.1852	37.2370	37.2888	37.3407
144	37.3926	37.4446	37.4966	37.5486	37.6006	37.6527	37.7049	37.7570	37.8092	37.8615
145	37.9138	37.9661	38.0184	38.0708	38.1232	38.1757	38.2282	38.2807	38.3332	38.3859
146	38.4385	38.4912	38.5439	38.5966	38.6494	38.7022	38.7551	38.8080	38.8609	38.9139
147	38.9669	39.0199	39.0730	39.1261	39.1792	39.2324	39.2856	39.3389	39.3922	39.4455
148	39.4988	39.5522	39.6057	39.6591	39.7126	39.7662	39.8197	39.8734	39.9270	39.9807
149	40.0344	40.0882	40.1420	40.1958	40.2496	40.3035	40.3575	40.4115	40.4655	40.5195
150	40.5736	40.6277	40.6819	40.7360	40.7903	40.8445	40.8988	40.9532	41.0075	41.0619
151	41.1164	41.1708	41.2254	41.2799	41.3345	41.3891	41.4438	41.4985	41.5522	41.6080
152	41.6628	41.7176	41.7725	41.8274	41.8823	41.9373	41.9923	41.0474	42.1025	42.1576
153	42.2128	42.2680	42.3232	42.3785	42.4338	42.4891	42.5445	42.5999	42.6554	42.7108
154	42.7664	42.8219	42.8775	42.9331	42.9888	43.0445	43.1003	43.1560	43.2118	43.2677
155	43.3236	43.3795	43.4354	43.4914	43.5475	43.6035	43.6596	43.7158	43.7719	43.8281

AREAS OF SEMI-SQUARES IN IMPERIAL GALLONS—*Continued.*

Sides in Ins.	0	1	2	3	4	5	6	7		9
156	43.8844	43.9407	43.9970	44.0533	44.1097	44.1661	44.2226	44.2791	44 3356	44.3922
157	44.4488	44.5055	44.5621	44.6188	44.6756	44.7324	44.7892	44.8461	44.9029	44.9599
158	45.0168	45.0738	45.1309	45.1880	45.2451	45.3022	45.3594	45.4166	45.4739	45.5312
159	45.5885	45.6458	45.7032	45.7607	45.8181	45.8757	45.9332	45.9908	46.0484	46.1060
160	46.1637	46.2214	46.2792	46.3370	46.3948	46.4527	46.5106	46.5685	46.6265	46.6845
161	46.7426	46.8007	46.8588	46.9169	46.9751	47.0333	47.0916	47.1499	47.2082	47.2666
162	47.3250	47.3835	47.4420	47.5005	47.5590	47.6176	47.6762	47.7349	47.7936	47.8523
163	47.9111	47.9699	48.0287	48.0876	48.1465	48.2055	48.2645	48.3235	48.3825	48.4416
164	48.5008	48.5599	48.6191	48.6784	48.7376	48.7969	48.8563	48.9157	48.9751	49.0345
165	49.0940	49.1536	49.2131	49.2727	49.3324	49.3920	49.4517	49.5115	49.5712	49.6311
166	49.6909	49.7508	49.8107	49.8707	49.9307	49.9907	50.0508	50.1109	50.1710	50.2312
167	50.2914	50.3517	50.4119	50.4723	50.5326	50.5930	50.6534	50.7139	50.7744	50.8349
168	50.8955	50.9561	51.0168	51.0774	51.1382	51.1989	51.2597	51.3205	51.3814	51.4423
169	51.5032	51.5642	51.6252	51.6862	51.7473	51.8084	51.8696	51.9307	51.9920	51.0532
170	52.1145	52.1758	52.2372	52.2986	52.3600	52.4215	52.4830	52.5446	52.6062	52.6678
171	52.7294	52.7911	52.8528	52.9146	52.9764	53.0382	53.1001	53.1620	53.2240	53.2859
172	53.3480	53.4100	53.4721	53.5342	53.5964	53.6586	53.7208	53.7831	53.8454	53.9077
173	53.9701	54.0325	54.0949	54.1574	54.2199	54.2825	54.3451	54.4077	54.4704	54.5331
174	54.5958	54.6586	54.7214	54.7842	54.8471	54.9100	54.9730	55.0360	55.0990	55.1621
175	55.2252	55.2883	55.3515	55.4147	55.4779	55.5412	55.6045	55.6678	55.7312	55.7946
176	55.8581	55.9216	55.9851	56.0487	56.1123	56.1759	56.2396	56.3032	56.3671	56.4308
177	56.4947	56.5585	56.6224	56.6863	56.7503	56.8143	56.8783	56.9424	57.0065	57.0706
178	57.1348	57.1990	57.2633	57.3276	57.3919	57.4563	57.5206	57.5851	57.6495	57.7140
179	57.7786	57.8432	57.9078	57.9724	58.0371	58.1018	58.1666	58.2314	58.2962	58.3611
180	58.4260	58.4909	58.5559	58.6209	58.6859	58.7510	58.8161	58.8813	58.9465	59.0117
181	59.0769	59.1422	59.2076	59.2729	59.3383	59.4038	59.4693	59.5348	59.6003	59.6659
182	59.7315	59.7972	59.8629	59.9286	59.9944	60.0602	60.1260	60.1919	60.2578	60.3237
183	60.3897	60.4557	60.5218	60.5879	60.6540	60.7202	60.7864	60.8526	60.9189	60.9852
184	61.0515	61.1179	61.1843	61.2508	61.3173	61.3838	61.4503	61.5169	61.5836	61.6502
185	61.7169	61.7837	61.8504	61.9173	61.9841	62.0510	62.1179	62.1849	62.2519	62.3189
186	62.3859	62.4530	62.5202	62.5874	62.6546	62.7218	62.7891	62.8564	62.9238	62.9911
187	63.0586	63.1260	63.1935	63.2611	63.3286	63.3962	63.4639	63.5315	63.5993	63.6670
188	63.7348	63.8026	63.8705	63.9384	64.0063	64.0743	64.1423	64.2103	64.2784	64.3465
189	64.4146	64.4828	64.5510	64.6193	64.6876	64.7559	64.8243	64.8927	64.9611	65.0296
190	65.0981	65.1666	65.2352	65.3038	65.3724	65.4411	65.5099	65.5786	65.6474	35.7162
191	65.7851	65.8540	65.9229	65.9919	66.0609	66.1300	66.1991	66.2682	66.3373	66.4065
192	66.4758	66.5450	66.6143	66.6837	66.7530	66.8224	66.8919	66.9614	67.0309	67.1004
193	67.1700	67.2396	67.3093	67.3790	67.4487	67.5185	67.5883	67.6581	67.7280	67.7979
194	67.8679	67.9379	68.0079	68.0779	68.1480	68.2182	68.2883	68.3585	68.4286	68.4990
195	68.5694	68.6397	68.7101	68.7805	68.8510	68.9214	68.9920	69.0625	69.1331	69.2038
196	69.2744	69.3451	69.4159	69.4867	69.5575	69.6283	69.6992	69.7701	69.8411	69.9121
197	69.9831	70.0542	70.1253	70.1964	70.2676	70.3388	70.4101	70.4813	70.5527	70.6240
198	70.6954	70.7668	70.8383	70.9098	70.9813	71.0529	71.1245	71.1962	71.2678	71.3396
199	71.4113	71.4831	71.5549	71.6268	71.0987	71.7706	71.8426	71.9146	71.9866	72.0587
200	72.1308	72.2030	72.2752	72.3474	72.4196	72.4919	72.5643	72.6366	72.7090	72.7815

CHAPTER XXII.

CONVERSION FACTORS.

THE use of metric units on the continent of Europe for industrial and commercial purposes, their use in this country in chemical, metallurgical, and physical calculations, makes it often necessary to convert our customary English measures into metric units or vice versa. The following table, compiled by C. W. Hunt, is very useful in this regard:

Millimeters × .03937 = inches.
Millimeters ÷ 25.4 = inches.
Centimeters × .3937 = inches.
Centimeters ÷ 2.54 = inches.
Meters × 39.37 = ins. (Act Congress).
Meters × 3.281 = feet.
Meters × 1.094 = yards.
Kilometers × .621 = miles.
Kilometers ÷ 1.6093 = miles.
Kilometers × 3280.8693 = feet.
Square millimeters × .00155 = sq. ins.
Square millimeters ÷ 645.1 = sq. ins.
Square centimeters × .155 = sq. inches.
Square centimeters ÷ 6.451 = sq. ins.
Square meters × 10.764 = square feet.
Square kilometers × 247.1 = acres.
Hectare × 2.471 = acres.
Cu. centimeters ÷ 16.383 = cu. inches.
Cu. centimeters ÷ 3.69 = fluid drams (U. S. P.).
Cu. cent. ÷ 29.57 = fl. oz. (U. S. P.).
Cubic meters × 35.315 = cubic feet.
Cubic meters × 1.308 = cubic yards.
Cubic meters × 264.2 = gallons (231 cu. in.).
Liters × 61.022 = cu. in. (Act Cong.).
Liters × 33.84 = fl. oz. (U. S. P.).
Liters × .2642 = gallons (231 cu. in.).
Liters ÷ 3.78 = gallons (231 cu. in.).
Liters ÷ 28.316 = cubic feet.
Hectoliters × 3.531 = cubic feet.
Hectoliters × 2.84 = bushels (2150.42 cu. in.).
Hectoliters × .131 = cubic yards.
Hectoliters ÷ 26.42 = gals. (231 cu. in.).
Grammes × 15.432 = grains (Act Congress).
Grammes ÷ 981 = dynes.
Grammes (water) ÷ 29.57 = fl. ounces.
Grammes ÷ 28.35 = ounces avoir.
Grammes per cu. cent. ÷ 27.7 = lbs. per cu. in.
Joule × .7373 = foot-pounds.
Kilogrammes × 2.2046 = pounds.
Kilogrammes × 35.3 = ounces avoir.
Kilogms. ÷ 907.2 = tons (2000 lbs.).
Kilogms. per sq. cent. × 14.223 = lbs. per square inch.
Kilogram-meters × 7.233 = ft.-lbs.
Kilogms. per meter × .672 = lbs. per ft.
Kilogms. per cu. meter × .062 = lbs. per cubic foot.
Kilogms. per cheval × 2.235 = lbs. per horse-power.
Kilowatts × 1.34 = horse-power.
Watts ÷ 746 = horse-power.
Watts × .7373 = ft.-lbs. per second.
Calorie × 3.968 = B.t.u.
Cheval vapeur × .9863 = horse-power.
(Centigrade × 1.8) + 32 = deg. Fahr.
Franc × .193 = dollars.
Gravity Paris = 980.94 centimeters per second.

REDUCTION OF FRENCH AND ENGLISH MEASURES.

One meter	39.37043 inches 3.28087 feet
One cubic meter	35.314 cubic feet 1.308 cubic yards
One cubic yard	0.7645 cubic meters
One cubic foot	0.02832 cubic meters
One cubic decimeter	61.023 cubic inches 0.0353 cubic feet
One cubic foot	28.32 cubic decimeters
One cubic centimeter	0.061 cubic inches
One cubic inch	16.387 cubic centimeters
One liter (0.001 cubic meter or one cubic decimeter)	61.023 cubic inches 0.03531 cubic feet 2.1135 pints 1.0567 quarts (American) 0.2642 gallons (American) 2.202 pounds of water at 62° F.
One cubic foot	~~28.317~~ liters 2.8317
One gallon (American, 231 cubic inches)	3.785 liters
One gallon (British, 277.274 cubic inches)	4.543 liters
One quart (57.75 cubic inches)	946.30 cubic centimeters
One pint (28.875 cubic inches)	473.15 cubic centimeters
One milligramme	0.015432 grains
One grain	64.799 milligrammes
One gramme	15.43235 grains
One grain	0.064799 grammes
One gramme	0.03215 ounces (troy)
One ounce (troy, 480 grains)	31.10348 grammes

	Milligrammes to Grains.	Grains to Milligrammes.	Grammes to Grains.	Grains to Grammes.	Grammes to Ounces (Avoirdupois).
1	0.01543	64.7989	15.43235	0.064799	0.035274
2	0.03086	129.5978	30.86470	0.129598	0.070548
3	0.04630	194.3968	46.29705	0.194397	0.105822
4	0.06173	259.1957	61.72940	0.259196	0.141096
5	0.07716	323.9946	77.16175	0.323995	0.176370
6	0.09259	388.7935	92.59100	0.388794	0.211644
7	0.10803	453.5924	108.02645	0.453593	0.246918
8	0.12346	518.3914	123.45880	0.518392	0.282192
9	0.13889	583.1903	138.89115	0.583191	0.317466
10	0.15430	647.9890	154.32350	0.647990	0.352740

One gramme..................	0.035274 ounces (avoirdupois)
One ounce (avoirdupois, 437.50 grains)..................	28.35 grammes
One kilogramme................	2.2046 pounds (avoirdupois)
One pound (avoirdupois, 7000 grains)..................	0.45359 kilogrammes
One pound (troy, 5760 grains)...	0.37324 kilogrammes

Ounces (Avoirdupois) to Grammes.	Grammes to Ounces (Troy).	Ounces (Troy) to Grammes.	Kilogrammes to Pounds (Avoirdupois).	Pounds (Avoirdupois) to Kilogrammes.
28.3495	0.03215	31.10348	2.20462	0.45359
56.6991	0.06430	62.20696	4.40924	0.90719
85.0486	0.09645	93.31044	6.61386	1.36078
113.3981	0.12860	124.41392	8.81849	1.81437
141.7476	0.16075	155.51740	11.02311	2.26796
170.0972	0.19290	186.62089	13.22773	2.72156
198.4467	0.22505	217.72437	15.43235	3.17515
226.7962	0.25721	248.82785	17.63697	3.62874
255.1457	0.28936	279.93133	19.84159	4.08233
283.4950	0.32150	311.03480	22.04620	4.53590

EQUIVALENTS OF WORK AND HEAT.

1	B.t.u.	= 778	ft.-lbs.	= 17.59	watts.		
42.41	"	= 33000	"	= 746	"	=	1 H.P. .

In the French or metric system of units, a heat-unit or calorie is the quantity of heat required to raise 1 kilogramme of pure water 1° C. at or about 4° C.

The following tabular statement shows the relation of the French and English units:

FRENCH AND ENGLISH UNITS COMPARED.

1 calorie..................................	3.968 B.t.u.
0.252 calorie..............................	1 "
French mechanical equivalent, 425.0 kilogram-meters..............................	3075 ft.-lbs.
107.7 kilogram-meters.....................	1, or 778 ft.-lbs.

For convenience in translating French and German results into English or American we have the following compound units:

EQUIVALENT COMPOUND UNITS.

1 calorie per square meter........	0.369 B.t.u. per square foot
1 B.t.u. or 1 H.u. per square foot..	2.713 calories per square meter
1 calorie per kilogramme.........	1.800 H.u. per pound
1 H.u. per pound................	0.556 calorie per kilogramme

CONVERSION OF HEAT-UNITS.

	Calories per Kilogramme to British Thermal Units per Pound	Calories per Cubic Meter to British Thermal Units per Cubic Foot.	British Thermal Units per Pound to Calories per Kilogramme.	British Thermal Units per Cubic Foot to Calories per Cubic Meter.
1	1 8	0.11236	0 556	8 898
2	3.6	.22472	1.112	17 796
3	5.4	.33708	1 668	26 694
4	7 2	.44944	2 224	35 592
5	9.0	.56180	2.780	44.490
6	10.8	.67416	3 336	53.388
7	12.6	.78652	3 892	62 286
8	14 4	.89888	4 448	71 184
9	16 2	1 01124	5.004	80 082
10	18.	1.1236	5 560	88 980
15	27.	1 6854	8 340	133 470
20	36	2 2472	11.120	177 960
25	45.	2 809	13 900	222 450
30	54	3.3708	16.680	266 940
35	63.	3 9326	19.460	311.430
40	72.	4 4944	22 240	355 920
45	81.	5.0562	25.020	400 410
50	90.	5.618	27 800	444.900
55	99.	6 1798	30 580	489 390
60	108.	6 7416	33 360	533 880
65	117.	7 3034	36 140	578 370
70	126.	7 8652	38 920	622 860
75	135.	8 427	41 700	667 350
80	144.	8 9888	44 480	711 840
85	153.	9 5506	47.260	756 330
90	162.	10 1124	50 040	800 820
95	171.	10 6742	52 820	845 310
100	180.	11 236	55 600	889 800
200	360.	22 472	111 200	1779 600
300	540.	33.708	116.800	2669.400
		44 944	222.400	359.200
400	720.	56 180	278	4419.
500	900.	67 416	333 600	5339.200
600	1080.	78.652	389 200	6228.600
700	1260.	[redacted]	444.800	7118.400
800	1440.	101.124	500.400	[redacted]
900	1620.	112.36	556.	8898.
1000	1800.			

CONVERSION OF DEGREES CENTIGRADE AND FAHRENHEIT.

In the centigrade thermometer the freezing-point of water is taken as 0°, and on the Fahrenheit scale as 32°. The boiling-point of water is taken as 100° on the former and as 212° on the latter. This gives a range of 100 degrees between the freezing- and boiling-points of water on the centigrade scale, and of 180 degrees on the Fahrenheit scale, or a ratio of 1 to 1.8. Hence to change degrees centigrade to Fahrenheit, multiply the degrees centigrade by 1.8 and add 32 to the product; and to change degrees Fahrenheit to centigrade, subtract 32 from the degrees Fahrenheit and multiply the remainder by the reciprocal of 1.8 or 0.556.

In the following tables are tabulated for convenience of use the comparative values on the two scales.

CONVERSION OF THERMOMETRIC READINGS.

Fahrenheit to Centigrade.

F.	C.	F.	C.	F.	C.	F.	C.
-40°	-40°	1°	-17.2°	41°	5.°	81°	27.2°
-39	-39.4	2	-16.6	42	5.5	82	27.7
-38	-38.8	3	-16.1	43	6.1	83	28.3
-37	-38.3	4	-15.5	44	6.6	84	28.8
-36	-37.7	5	-15.	45	7.2	85	29.4
-35	-37.2	6	-14.4	46	7.7	86	30.
-34	-36.6	7	-13.8	47	8.3	87	30.5
-33	-36.1	8	-13.3	48	8.8	88	31.1
-32	-35.5	9	-12.7	49	9.4	89	31.6
-31	-35.	10	-12.2	50	10.	90	32.2
-30	-34.4	11	-11.6	51	10.5	91	32.7
-29	-33.8	12	-11.1	52	11.1	92	33.3
-28	-33.3	13	-10.5	53	11.6	93	33.8
-27	-32.7	14	-10.	54	12.2	94	34.4
-26	-32.2	15	-9.4	55	12.7	95	35.
-25	-31.6	16	-8.8	56	13.3	96	35.5
-24	-31.1	17	-8.3	57	13.8	97	36.1
-23	-30.5	18	-7.7	58	14.4	98	36.6
-22	-30.	19	-7.2	59	15.	99	37.2
-21	-29.4	20	-6.6	60	15.5	100	37.7
-20	-28.8	21	-6.1	61	16.1	101	38.3
-19	-28.3	22	-5.5	62	16.6	102	38.8
-18	-27.7	23	-5.	63	17.2	103	39.4
-17	-27.2	24	-4.4	64	17.7	104	40.
-16	-26.6	25	-3.8	65	18.3	105	40.5
-15	-26.1	26	-3.3	66	18.8	106	41.1
-14	-25.5	27	-2.7	67	19.4	107	41.6
-13	-25.	28	-2.2	68	21.1	108	42.2
-12	-24.4	29	-1.6	69	20.	109	42.7
-11	-23.8	30	-1.1	70	20.5	110	43.3
-10	-23.3	31	-0.5	71	21.6	111	43.8
-9	-22.7	32	+0	72	22.2	112	44.4
-8	-22.2	33	+0.5	73	22.7	113	45.
-7	-21.6	34	1.1	74	23.3	114	45.5
-6	-21.1	35	1.6	75	23.8	115	46.1
-5	-20.5	36	2.2	76	24.4	116	46.6
-4	-20.	37	2.7	77	25.	117	47.2
-3	-19.4	38	3.3	78	25.5	118	47.7
-2	-18.8	39	3.8	79	26.1	119	48.3
-1	-18.3	40	4.4	80	26.6	120	48.8
0	-17.7						

CONVERSION OF THERMOMETRIC READINGS—*Continued.*

Fahrenheit to Centigrade.

F.	C.	F.	C.	F.	C.	F.	C.
121°	49.4°	161°	71.6°	201°	93.8°	241°	116.1°
122	50.	162	72.2	202	94.4	242	116.6
123	50.5	163	72.7	203	95.	243	117.2
124	51.1	164	73.3	204	95.5	244	117.7
125	51.6	165	73.8	205	96.1	245	118.3
126	52.2	166	74.4	206	96.6	246	118.8
127	52.7	167	75.	207	97.2	247	119.4
128	53.3	168	75.5	208	97.7	248	120.
129	53.8	169	76.1	209	98.3	249	120.5
130	54.4	170	76.6	210	98.8	250	121.1
131	55.	171	77.2	211	99.4	251	121.6
132	55.5	172	77.7	212	100.	252	122.2
133	56.1	173	78.3	213	100.5	253	122.7
134	56.6	174	78.8	214	101.1	254	123.3
135	57.2	175	79.4	215	101.6	255	123.8
136	57.7	176	80.	216	102.2	256	124.4
137	58.3	177	80.5	217	102.7	257	125.
138	58.8	178	81.1	218	103.3	258	125.5
139	59.4	179	81.6	219	103.8	259	126.1
140	60.	180	82.2	220	104.4	260	126.6
141	60.5	181	82.7	221	105.	261	127.2
142	61.1	182	83.3	222	105.5	262	127.7
143	61.6	183	83.8	223	106.1	263	128.3
144	62.2	184	84.4	224	106.6	264	128.8
145	62.7	185	85.	225	107.2	265	129.4
146	63.3	186	85.5	226	107.7	266	130.
147	63.8	187	86.1	227	108.3	267	130.5
148	64.4	188	86.6	228	108.8	268	131.1
149	65.	189	87.2	229	109.4	269	131.6
150	65.5	190	87.7	230	110.	270	132.2
151	66.1	191	88.3	231	110.5	271	132.7
152	66.6	192	88.8	232	111.1	272	133.3
153	67.2	193	89.4	233	111.6	273	133.8
154	67.7	194	90.	234	112.2	274	134.4
155	68.3	195	90.5	235	112.7	275	135.
156	68.8	196	91.1	236	113.3	276	135.5
157	69.4	197	91.6	237	113.8	277	136.1
158	70.	198	92.2	238	114.4	278	136.7
159	70.5	199	92.7	239	115.	279	137.2
160	71.1	200	93.3	240	115.5		

USEFUL FACTORS.

Inches	×	0.08333	= feet
Inches	×	0.02778	= yards
Inches	×	0.00001578	= miles
Square inches	×	0.00695	= square feet
Square inches	×	0.0007716	= square yards
Cubic inches	×	0.00058	= cubic feet
Cubic inches	×	0.0000214	= cubic yards
Cubic inches	×	0.004329	= U. S. gallons
Feet	×	0.3334	= yards
Feet	×	0.00019	= miles
Square feet	×	144.00	= square inches
Square feet	×	0.1112	= square yards
Cubic feet	×	1728.00	= cubic inches
Cubic feet	×	0.03704	= cubic yards
Cubic feet	×	7.48	= U. S. gallons
Yards	×	36.000	= inches
Yards	×	3.000	= feet
Yards	×	0.0005681	= miles
Square yards	×	1296.000	= square inches
Square yards	×	9.000	= square feet
Cubic yards	×	46656.000	= cubic inches
Cubic yards	×	27.000	= cubic feet
Miles	×	63360.000	= inches
Miles	×	5280.000	= feet
Miles	×	1760.00	= yards
Avoir. oz.	×	0.0625	= pounds
Avoir. oz.	×	0.00003125	= tons
Avoir. lbs.	×	16.000	= ounces
Avoir. lbs.	×	0.001	= hundredweight
Avoir. lbs.	×	0.0005	= tons
Avoir. lbs.	=	27.681	cu. inches of water at 39.2° F.
Avoir. tons	×	32000.00	= ounces
Avoir. tons	×	2000.00	= pounds
Watts	×	746.00	= horse-power
Horse-power	×	0.00134	= watts

Weight of round iron per foot = square of diameter in quarter inches ÷ 6.

Weight of flat iron per foot = width × thickness × 10.3.

Weight of flat plates per square foot = 5 pounds for each ⅛ inch thickness.

Weight of chain = diameter squared × 10.7 (approximately).

Safe load (in pounds) for chains = square of quarter inches in diameter of bar.

WATER FACTORS.

U. S. gallons	× 8.33	= pounds
U. S. gallons	× 0.13368	= cubic feet
U. S. gallons	× 231.00	= cubic inches
U. S. gallons	× 0.83	= English gallons
U. S. gallons	× 3.78	= liters
English gallons (Imperial)	× 10	= pounds
English gallons (Imperial)	× 0.16	= cubic feet
English gallons (Imperial)	× 277.274	= cubic inches
English gallons (Imperial)	× 1.2	= U. S. gallons
English gallons (Imperial)	× 4.537	= liters
Cubic feet (of water) (39.1°)	× 62.425	= pounds
Cubic feet (of water) (39.1°)	× 7.48	= U. S. gallons
Cubic feet (of water) (39.1°)	× 6.232	= English gallons
Cubic feet (of water) (39.1°)	× 0.028	= tons
Cubic foot of ice	× 57.2	= pounds
Cubic inches of water (39.1°)	× 0.036024	= pounds
Cubic inches of water (39.1°)	× 0.004329	= U. S. gallons
Cubic inches of water (39.1°)	× 0.003607	= English gallons
Cubic inches of water (39.1°)	× 0.576384	= ounces
Pounds of water	× 27.72	= cubic inches
Pounds of water	× 0.01602	= cubic feet
Pounds of water	× 0.083	= U. S. gallons
Pounds of water	× 0.10	= English gallons
Tons of water	× 268.80	= U. S. gallons
Tons of water	× 224.00	= English gallons
Tons of water	× 35.90	= cubic feet
Ounces of water	× 1.735	= cubic inches

A column of water 1 inch square by 1 foot high weighs 0.434 pound.

A column of water 1 inch square by 2.31 feet high weighs 1.000 pound.

Water is at its greatest density at 39.2° F.

Sea water is 1.6 to 1.9 heavier than fresh.

One cubic inch of water makes approximately 1 cubic foot of steam at atmospheric pressure.

27222 cubic feet of steam at atmospheric pressure weigh 1 pound.

CHAPTER XXIII.

PIPE AND MISCELLANEOUS DATA.

THE formula generally used for calculating the capacity of a pipe for transmitting gas under low pressures not exceeding the head due to a few inches of water column is credited to Dr. Pole and is

$$Q=1350\sqrt{\frac{d^5h}{lg}},$$

where Q = cu. ft. discharged at the exit end per hour;
d = internal diameter, inches;
h = pressure in inches of water column;
l = length of pipe in yards;
g = specific gravity of the gas, air = 1.

Prof. S. W. Robinson of Columbus, Ohio, has deduced the following formula for high pressures, which is slightly in excess of the observed results:

$$V=48.4\frac{T_1}{\sqrt{T_2T_0}}\sqrt{\frac{d^5}{L}(p_1+p_2+30)\ (p_1-p_2)\frac{\text{[illegible]}}{g}},$$

where V = cubic feet per hour at atmospheric pressure and T_1;
T_1 = absolute temperature of storage = 461° + reading F°;
T_2 = absolute temperature of gas flowing in pipe-line reading F°;
T_0 = absolute temperature = 461° + 37° F. = 498° (at maximum density of water);
d_5 = diameter of pipe-line in inches;
L = length of pipe-line in miles;
p_1 = gage pressure at entrance end of gas-main, pounds per square inch;
p_2 = gage pressure at exit end of main, pounds per square inch.

Some of the data found valuable in connection with pipe are given herewith in the following tables:

WROUGHT-IRON WELDED PIPE.

(1 in. diam. and below are butt-welded and tested to 300 lbs. per sq. in. hydraulic pressure; 1¼ in. and above are lap-welded and tested to 500 lbs. per sq. in. hydraulic pressure.)

Inside Diameter.	Outside Diameter.	External Circumference.	Length of Pipe per Sq. Ft. of Outside Surface.	Internal Area.	External Area	Length of Pipe containing 1 Cubic Foot.	Weight per Foot of Length.	No. of Threads per Inch per Screw.	Contents in Gallons* per Foot.	Weight of Water per Foot of Length.
Inch.	Inch.	Inches.	Feet.	Inches.	Inches.	Feet.	Lbs.			Lbs.
⅛	0.40	1.272	9.440	0.012	0.129	2500.0	0.24	27	0.0006	0.005
¼	0.54	1.696	7.075	0.049	0.229	1385.0	0.42	18	0.0026	0.021
⅜	0.67	2.121	5.657	0.110	0.358	751.5	0.56	18	0.0057	0.047
½	0.84	2.652	4.502	0.196	0.554	472.4	0.84	14	0.0102	0.085
¾	1.05	3.299	3.637	0.441	0.866	270.0	1.12	14	0.0230	0.190
1	1.31	4.134	2.903	0.785	1.357	166.9	1.67	11½	0.0408	0.349
1¼	1.66	5.215	2.301	1.227	2.164	96.25	2.25	11½	0.0638	0.527
1½	1.9	5.969	2.01	1.767	2.835	70.65	2.69	11½	0.0918	0.760
2	2.37	7.461	1.611	3.141	4.430	42.36	3.66	11½	0.1632	1.356
2½	2.87	9.032	1.328	4.908	6.491	30.11	5.77	8	0.2550	2.116
3	3.5	10.996	1.091	7.068	9.621	19.49	7.54	8	0.3673	3.049
3½	4.	12.566	0.955	9.621	12.566	14.56	9.05	8	0.4998	4.155
4	4.5	14.137	0.849	12.566	15.904	11.31	10.72	8	0.6528	5.405
4½	5.	15.708	0.765	15.904	19.635	9.03	12.49	8	0.8263	6.851
5	5.56	17.475	0.629	19.635	24.299	7.20	14.56	8	1.020	8.500
6	6.62	20.813	0.577	28.274	34.471	4.98	18.76	8	1.469	12.312
7	7.62	23.954	0.505	38.484	45.663	3.72	23.41	8	1.999	16.662
8	8.62	27.096	0.444	50.265	58.426	2.88	28.34	8	2.611	21.750
9	9.68	30.433	0.394	63.617	73.715	2.26	34.67	8	3.300	27.500
10	10.75	33.772	0.355	78.540	90.792	1.80	40.64	8	4.081	34.000

* The Standard U. S. gallon of 231 cubic inches.

Equation of Pipes.—It is frequently desired to know what number of pipes of a given size are equal in carrying capacity to one pipe of a larger size. At the same velocity of flow the volume delivered by two pipes of different sizes is proportional to the squares of their diameters; thus, one 4-inch pipe will deliver the same volume as four 2-inch pipes. With the same head, however, the velocity is less in the smaller pipe and the volume delivered varies about as the square root of the fifth power (i.e., as the 2.5 power). The following table has been calculated on this basis. The figures opposite the intersection of any two sizes is the number of the smaller-sized pipes required to equal one of the larger. Thus, one 4-inch pipe is equal to 5.7 2-inch pipes.

EQUATION OF PIPES.

Diam., Inches.	1	2	3	4	5	6	7	8	9	10	12	14	16	18	20	24
2	5.7	1														
3	15.6	2.8	1													
4	32	5.7	2.1	1												
5	55.9	9.9	3.6	1.7	1											
6	88 2	15.6	5.7	2 8	1.6	1										
7	130	22.9	8.3	4.1	2.3	1.5	1									
8	181	32	11.7	5.7	3.2	2.1	1.4	1								
9	243	43	16.6	7.6	4.3	2.8	1.9	1.3	1							
10	[illegible]	55 9	20.3	9 9	5.7	3.6	2.4	1.7	1.3	1						
11	401	70.9	25.7	12.5	7.2	4.6	3.1	2 2	1.7	1.3						
12	[illegible]	88.2	32	15.6	8.9	5.7	3.8	2.8	2 1	1.6	1					
13	609	108	39.1	19	10.9	7.1	4.7	3.4	2.5	1.9	1 2					
14	733	130	47	22.9	13.1	8.3	5.7	4 1	3.0	2.3	1.5	1				
15	787	154	55.9	27.2	15.6	9.9	6.7	4.8	3.6	2.8	1.7	1.2				
16	......	181	65.7	32	18.3	11.7	7.9	5.7	4.2	3 2	2.1	1.4	1			
17	......	211	76.4	37.2	21.3	13.5	9.2	6.6	4.9	3 8	2.4	1.6	1.2			
18	......	243	88.2	[illegible]	24.6	15 6	10 6	7.6	5 7	4.3	2.8	1.9	1.3	1		
19	......	278	101	49.1	28.1	17.8	12 1	8.7	6.5	5	3.2	2.1	1.5	1.1		
20	......	316	115	55.9	32	20.3	13.8	9.9	7.4	5.7	3 6	2.4	1.7	1.3	1	
22	......	401	146	70.9	40.6	25.7	17 5	12.5	9.3	7.2	4.6	3.1	2.2	1.7	1.3	
24	......	499	181	88.2	50.5	32	21 8	16.6	11.6	8.9	5.7	3.8	2.8	2.1	1.6	1
26	......	609	221	[illegible]	61.7	39.1	26.6	[illegible]	14.2	10.9	7 1	4.7	3.4	2.5	1.9	1.2
28	......	733	266	130	74.2	47	32	22.9	17.1	13.1	8 3	5.7	4.1	3	2.3	1.5
30	......	787	316	[illegible]	88.2	55.9	38	27.2	20.3	15.6	9 9	6.7	4.8	3.6	2.8	1.7
36	......	......	499	243	130	88.2	60	[illegible]	32	24.6	15.6	10.6	7.6	5.7	4.3	2 8
42	......	......	733	357	205	130	88.2	63.2	47	36 2	19	15 6	11.2	8.3	6.4	4.1
48	......	......	......	499	288	181	123	88.2	62.7	50 5	32	21 8	15.6	11.6	8 9	5.7
54	......	......	......	670	383	243	165	118	88.2	67.8	43	29.2	20.9	15.6	12	7.6
60	......	......	......	787	499	316	215	154	115	88.2	55.9	38	27.2	20.3	15.6	9.9

PIPING AND PIPE-FITTINGS.

The Crane Co. of Chicago, Ill., have conducted tests on piping, and some of the conclusions were presented in a paper before the Engine Builders' Association at the spring meeting, 1902, by J. B. Berryman. The following is abstracted:

Strength of Ordinary Commercial Pipe.—Tests of lengths taken at random out of stock: 8-in. stood 2000 lbs.; 10-in. 2300 lbs.; 12-in. 1500 lbs.; 16-in., $\frac{3}{8}$ in. thick, 800 lbs.; and 24-in., $\frac{3}{8}$ in. thick, 600 lbs. per sq. in. without rupture or distortion. Thousands of pieces of 20-in. size and under have stood 800 lbs. per sq. in. Hence there is no reason why pipe heavier than standard should be used in power plants, except where water is bad and there may be corrosion.

Flanged Joints.—Most of our orders are for screwed or shrunk flanges in the ratio of 85 screwed to 15 shrunk. We prefer the screwed joint and use the following lengths of thread, those first given being for pressures up to 125 lbs. and those in last column for pressure up to 250 lbs.

Diameter, Pipe.	Thread Lengths.	
4-in.	$1\frac{3}{16}$	$1\frac{3}{4}$
6-in.	$1\frac{7}{16}$	2
8-in.	$1\frac{5}{8}$	$2\frac{1}{16}$
12-in.	$2\frac{1}{16}$	$2\frac{9}{16}$
16-in.	$2\frac{7}{16}$	$2\frac{7}{8}$
20-in.	$2\frac{3}{4}$	$3\frac{1}{4}$

Assuming a shearing strength of one-half tensile strength, the above proportions give a holding power fully three times ultimate strength of pipe. We have tested joints, starting with long threads on pipe, as per above table, and gradually cutting threads away. In no case were threads stripped, and results show that strength of joints was limited by strengths of the cast-iron flanges. On a 10-inch pipe threads were reduced until only 5 remained. Flanges broke at 650 pounds pressure, all threads remaining intact. A calculation of the amount of metal which would have to be sheared off before a joint parted will show that there is no likelihood of the threads stripping. Taking our standard length of thread, eight per inch, the results work out as follows:

Size.	Length of Threads.	Metal in Contact, Square Inches.	Sectional Area of Full-weight Pipe.
8	$1\frac{5}{8}$	42	8.396
12	$2\frac{1}{16}$	77	14.579
$16\frac{3}{8}$	$2\frac{7}{16}$	116	18.41

Mess. Crane made a great number of tests on 8-in. pipe, using regular wrought-iron couplings to demonstrate that long threads are not necessary to strength. Final tests were made with barely 6 threads in contact, and ¾ inch length of threaded part. The pipe was tested to 1000 pounds, the pressure being held a day without giving way. The only object in using long threads is to make a tight joint and not to gain strength. Pipe should be screwed clear through flange to guard against vibration and make a bearing for gasket on end of pipe and close thread against oxidizing action of steam. Screw flange on by power until pipe projects 1/16 in.; then face off end of pipe and face true with axis of pipe. In making shrunk joints the pipe is rounded up and calipered, flange bored out to a shrinking-fit size, brought to red heat, the pipe slipped in and peened over.

Facing Flanges.—Flanges are generally made with straight face finished smooth, straight face finished corrugated, male and female, tongue and groove and 1/32 in. raised face inside bolt-holes. For pressure of 180 lbs. or less our experiments show that a straight, concentrically corrugated face will hold a Rainbow or copper gasket. Have made repeated tests with pressures up to 1000 pounds without blowing out the gasket.

Flanges.—There are two recognized standards for flanges. One, for pressures up to 125 lbs., was adopted by a joint committee of the A. S. M. E., the Master Steam Fitters' Association, and the manufacturers. The other, for pressures up to 250 lbs., was adopted at a meeting of the manufacturers held in New York, June 28, 1901, and is generally referred to as the "Manufacturers' Standard."

Flanged Fittings.—We manufacture these in three weights for pressures up to 50, 125, and 250 lbs. respectively. The thickness of the body metal of each is as follows:

Diameter Pipe.	Light.	Standard.	Extra Heavy.
6-in.		9/16	¾
10-in.		¾	15/16
12-in.	½	13/16	1
16-in.	⅝	1	1 3/16
20-in.	11/16	1⅛	1 5/16
24-in.	¾	1¼	1½

These thicknesses give factors of safety of 10 or 12, when computed by the formula for pipes, which is desirable, since tests show that fittings burst at pressures less than indicated by theory.

Valves.—Valves are made of same thickness as the flanged fittings and designed for corresponding pressures. The standard

valves, 4-in. to 8-in., will burst at about 700 lbs.; 10-in. to 16-in. at about 600 lbs. The extra heavy valves, 4-in. to 8-in., burst at 1600 to 1900 lbs.; 10-in. to 16-in. at about 1200 to 1500. A medium valve is also made for pressures between those for which the standard and extra-heavy valves are designed. In all these cases the valves were of the solid wedge type, and it was found that their disks would stand about 80 per cent. of the bursting pressure without leaking. It would not be possible to obtain equivalent results from parallel-seated double-disk valves, as their disks have comparatively light faces, set out by an internal wedging mechanism, and will spring under pressure. It is not considered desirable to rib the bodies of heavy valves owing to unequal strains. For high pressures use valves without outside screw and yoke.

Pipe-bends.—Unless of very short radius, they are generally made of standard pipe for pressures of 125 pounds or less, full-weight pipe up to 175 pounds, and extra-heavy pipe for higher pressures.

WHITWORTH'S SCREW-THREADS.

GAS- AND WATER-PIPING.

Diameter of Piping.		Diameter at Bottom of Thread.	No. of Threads per Inch.	Diameter of Piping		Diameter at Bottom of Thread.	No. of Threads per Inch.
Internal	External.			Internal	External		
1/8	0.3825	0.3367	28	1 7/8	2.245	2.1285	11
1/4	0.518	0.4506	19	2	2.347	2.2305	11
3/8	0.6563	0.5889	19	2 1/8	2.467	2.3505	11
1/2	0.8257	0.7342	14	2 1/4	2.5875	2.4710	11
5/8	0.9022	0.8107	14	2 3/8	2.794	2.3775	11
3/4	1.041	0.9495	14	2 1/2	3.0013	2.8848	11
7/8	1.189	1.0975	14	2 5/8	3.124	3.0075	11
1	1.309	1.1925	11	2 3/4	3.247	3.1305	11
1 1/8	1.492	1.3755	11	2 7/8	3.367	3.2505	11
1 1/4	1.650	1.5335	11	3	3.485	3.3685	11
1 3/8	1.745	1.6285	11	3 1/4	3.6985	3.5820	11
1 1/2	1.8825	1.7660	11	3 1/2	3.912	3.7955	11
1 5/8	2.021	1.9045	11	3 3/4	4.1255	4.0090	11
1 3/4	2.047	1.9305	11	4	4.339	4.2225	11

ELEMENTS OF STANDARD PIPE SECTIONS.

Nominal Size, Inches. N	Tap Drill. T	Outside Diameter D	Internal Diameter. d	Internal Area, Square Inch a	Area of Metal, Sq. In. A	Moment of Inertia. I	Section Modulus. $\frac{I}{\frac{1}{2}D}$	Radius of Gyration R	Square of Radius of Gyration. R^2	Weight per Foot in Pounds. W	Threads per Inch. t
1/8	11/32	0.405	0.27	0.0573	0.072	0.001	0.005	0.122	0.015	0.241	27
1/4	7/16	0.54	0.364	0.1041	0.125	0.003	0.012	0.163	0.027	0.420	18
3/8	9/16	0.675	0.494	0.1917	0.166	0.007	0.022	0.209	0.044	0.559	18
1/2	11/16	0.84	0.623	0.3048	0.249	0.017	0.041	0.262	0.068	0.837	14
3/4	29/32	1.05	0.824	0.5333	0.333	0.037	0.071	0.334	0.111	1.12	14
1	1 3/16	1.315	1.048	0.8626	0.495	0.107	0.162	0.343	0.118	1.68	11½
1¼	1½	1.66	1.38	1.496	0.668	0.195	0.235	0.540	0.291	2.24	11½
1½	1¾	1.9	1.611	2.038	0.797	0.309	0.325	0.681	0.463	3.68	11½
2	2¼	2.375	2.067	3.356	1.07	0.666	0.561	0.787	0.620	4.61	11½
2½	2 11/16	2.875	2.468	4.784	1.71	1.53	1.07	0.947	0.898	5.74	8
3	3 5/16	3.5	3.067	7.388	2.24	3.02	1.73	1.16	1.35	7.54	8
3½	3 13/16	4.0	3.548	9.887	2.68	4.79	2.39	1.34	1.79	9.00	8
4	4 5/16	4.5	4.026	12.73	3.17	7.23	3.21	1.51	2.28	10.7	8
4½	....	5.0	4.508	15.96	3.67	10.41	4.16	1.68	2.83	12.3	8
5	....	5.563	5.045	19.99	4.32	15.2	5.47	1.88	3.52	14.5	8
6	....	6.625	6.065	28.89	5.58	28.2	8.50	2.25	5.04	18.8	8
7	....	7.625	7.023	38.74	6.93	46.5	12.2	2.59	6.72	23.3	8
8	....	8.625	7.982	50.04	8.39	72.4	16.8	2.94	8.63	28.2	8
9	....	9.625	8.937	62.73	10.03	108.	22.9	3.28	10.8	33.7	8
10	....	10.75	10.019	78.84	11.92	161.	29.9	3.67	13.5	40.1	8
11	....	12.00	11.25	99.40	13.70	232.	38.6	4.12	16.9	46.0	8
12	....	12.75	12.00	113.1	14.58	279.	42.8	4.38	19.2	49.0	8
14 O. D.	....	14.00	13.25	137.9	16.05	373.	53.3	4.82	23.2	53.9	8
15 O. D.	....	15.00	14.25	159.5	17.23	461.	61.5	5.15	26.5	57.9	8
16 O. D.	....	16.00	15.25	182.6	18.41	562.	70.3	5.53	30.5	61.8	8

ELEMENTS OF EXTRA-STRONG PIPE SECTIONS.

Nominal Size, Inches. N	Outside Diameter. D	Internal Diameter. d	Internal Area, Sq In. a	Area of Metal, Sq In A	Moment of Inertia I	Section Modulus. $\frac{I}{\frac{1}{2}D}$	Radius of Gyration R	Square of Radius of Gyration. R^2	Weight per Foot in Pounds. W
⅛	0.405	0.205	0.033	0.066	0.001	0.006	0.114	0.013	0.29
¼	0.54	0.294	0.068	0.161	0.004	0.014	0.154	0.024	0.54
⅜	0.675	0.425	0.139	0.219	0.009	0.025	0.200	0.040	0.74
½	0.84	0.542	0.231	0.323	0.0[illegible]0	0.048	0.250	0.062	1.09
¾	1.05	0.[illegible]	0.452	0.414	0.045	0.086	0.321	0.103	1.39
1	1.315	0.951	0.710	0.648	0.107	0.162	0.406	0.165	0.217
1¼	1.66	1.272	1.27	0.893	0.244	0.270	0.523	0.273	3.00
1½	1.9	1.494	1.75	1.08	0.395	0.416	0.605	0.365	3.63
2	2.375	1.933	2.94	1.50	0.877	0.738	0.766	0.586	5.02
2½	2.875	2.315	4.21	2.28	1.94	1.35	0.923	0.852	7.67
3	3.5	2.892	6.57	3.05	3.93	2.28	1.14	1.29	10.3
3½	4.0	3.358	8.86	3.71	6.33	3.16	1.31	1.70	12.5
4	4.5	3.818	11.45	4.45	9.72	4.32	1.48	2.18	15.0
5	5.563	4.813	18.19	6.12	20.7	7.43	1.84	3.38	20.5
6	6.625	5.750	25.97	8.51	40.9	12.4	2.19	4.81	28.6

ELEMENTS OF DOUBLE EXTRA-STRONG PIPE SECTIONS

Nominal Size, Inches. N	Outside Diameter. D	Internal Diameter. d	Internal Area, Sq In. a	Area of Metal, Sq In A	Moment of Inertia I	Section Modulus. $\frac{I}{\frac{1}{2}D}$	Radius of Gyration R	Square of Radius of Gyration. R^2	Weight per Foot in Pounds. W
½	0.84	0.244	0.047	0.507	0.024	0.058	0.213	0.048	1.70
¾	1.05	0.422	0.139	0.727	0.058	0.111	0.283	0.080	2.44
1	1.315	0.587	0.271	1.09	0.141	0.214	0.360	0.130	3.65
1¼	1.66	0.885	0.615	1.55	0.343	0.413	0.471	0.221	5.20
1½	1.9	1.088	0.93	1.91	0.571	0.601	0.547	0.300	6.40
2	2.375	1.491	1.74	2.69	1.32	1.11	0.701	0.491	9.02
2½	2.875	1.755	2.42	4.07	2.89	2.01	0.842	0.709	13.7
3	3.5	2.284	4.10	5.52	6.03	3.45	1.05	1.09	18.6
3½	4.0	2.716	5.79	6.77	9.90	4.95	1.21	1.46	22.7
4	4.5	3.136	7.72	8.18	15.4	6.84	1.37	1.88	27.5
5	5.563	4.063	12.97	11.34	33.6	12.1	1.72	2.96	38.1
6	6.625	4.875	18.67	15.90	66.9	20.2	2.06	4.23	53.1

STANDARD WROUGHT-IRON AND STEEL-PIPE DIMENSIONS.

(Pipes $1\frac{1}{4}$ in. diam. and smaller are butt welded; $1\frac{1}{2}$ in. diam. and larger are lap welded.)

Size, Diam., Inches.	Thickness of Wall, Inches.	Area of Opening. Sq. Inches.	Actual Outside Diameter, Inches.	Nominal Weight per Foot, Lbs.	Number of Threads per Inch of Screw.
$\frac{1}{8}$	0.068	0.0573	0.405	0.24	27
$\frac{1}{4}$	0.088	0.1041	0.54	0.42	18
$\frac{3}{8}$	0.091	0.1917	0.675	0.56	18
$\frac{1}{2}$	0.109	0.3048	0.84	0.84	14
$\frac{3}{4}$	0.113	0.5333	1.05	1.12	14
1	0.134	0.8626	1.315	1.67	$11\frac{1}{2}$
$1\frac{1}{4}$	0.140	1.496	1.66	2.24	$11\frac{1}{2}$
$1\frac{1}{2}$	0.145	2.038	1.9	2.68	$11\frac{1}{2}$
2	0.154	3.356	2.375	3.61	$11\frac{1}{2}$
$2\frac{1}{2}$	0.204	4.784	2.875	5.74	8
3	0.217	7.388	3.5	7.54	8
$3\frac{1}{2}$	0.226	9.887	4.	9.	8
4	0.237	12.73	4.5	10.66	8
$4\frac{1}{2}$	0.246	15.961	5.	12.49	8
5	0.259	19.99	5.563	14.5	8
6	0.28	28.888	6.625	18.76	8
7	0.301	38.738	7.625	23.27	8
8	0.322	50.04	8.625	28.18	8
9	0.344	62.73	9.625	33.7	8
10	0.366	78.839	10.75	40.	8
11	0.375	95.033	11.75	45.	8
12	0.375	113.098	12.75	49.	8
13	0.375	137.887	14.	54.	8
14	0.375	159.485	15.	58.	8
15	0.375	187.04	16.	62.	8

WEIGHT OF MALLEABLE-IRON FITTINGS FOR GAS-PIPE.

Size, Inches.	Lbs. per Hundred
Elbows, 90 Degrees.	
⅛	8
¼×⅛	7½
¼	8½
⅜×⅛	14½
⅜×¼	14
⅜	15
½×¼	22½
½×⅜	19½
½	22
¾×⅜	31
¾×½	35
¾	33½
1×½	47½
1×¾	45
1	42½
1¼×¾	83
1¼×1	88½
1¼	76
1½×¾	102½
1½×1	94½
1½×1¼	101
1½	105
2×1¼	176
2×1½	169
2	169½
Elbows, 45 Degrees.	
8	12½
½	116½
¾	31
1	49
1¼	83½
1½	118
2	170
Street Elbows.	
⅜	16
½	26
¾×½	44
¾	47
1×¾	72
1	73
1¼×1	107
1¼	114
1½×1¼	153
1½	158
2×1½	229
2	260

Size, Inches.	Lbs. per Hundred.
Short Female Drop Elbows.	
¼	13
⅜×¼	22
⅜	19
½×⅜	27
½	27
¾×½	40½
¾	41½
Short Male and Female Drop Elbows.	
¼×⅜	12
½×⅜	16½
[illegible]	26
Long Male and Female Drop Elbows.	
½×⅜	16
½	26
Side Outlet Elbows.	
⅜×⅜×¼	12
⅜	16
½×½×⅜	19½
½	29
¾×¾×⅜	37
¾×¾×½	38
¾	40
1×1×⅜	48
1×1×½	49½
1×1×¾	51½
1	55½
1¼×1¼×1	87
1¼	91½
Tees.	
⅛	9
¼×⅛	[illegible]
¼×⅛	9½
¼	12
¼×⅜	16
⅜×¼×¼	15
⅜×¼×⅜	18½
⅜×⅛	16
⅜×¼	15
⅜	16½
⅜×½	24
⅜×¾	27
½×¼×¼	18½

Size, Inches.	Lbs. per Hundred.
Tees.	
½×¼×½	22
½×⅜×¼	20
½×⅜×⅜	24½
½×⅜×½	26½
½×⅜×¾	32½
½×¼	21
½×⅜	21¾
½	26
½×¾	29½
½×1	34½
½×1¼	75
¾×⅜×⅜	[illegible]
¾×⅜×½	35½
¾×⅜×¾	30½
¾×⅜×1	50
¾×½×¼	33
¾×½×⅜	29
¾×½×½	34
¾×½×¾	38
¾×½×1	50½
¾×¼	29½
¾×⅜	30½
¾×½	34
¾	41
¾×1	34
¾×1¼	64
¾×1½	69
1×⅜×½	44½
1×⅜×¾	47½
1×⅜×1	54
1×⅜×1¼	67½
1×½×⅜	37½
1×½×½	42
1×½×¾	40½
1×½×1	48
1×½×1¼	68
1×¾×⅜	39½
1×¾×½	44
1×¾×¾	38
1×¾×1	49
1×¾×1¼	67½
1×¼	37
1×⅜	35
1×½	41½
1×¾	50½
1	53
1×1¼	60½

WEIGHT OF MALLEABLE-IRON FITTINGS FOR GAS-PIPE—*Continued.*

Size, Inches.	Lbs. per Hundred.
Tees.	
1×1½	109
1¼×⅜×1	83
1¼×⅜×1¼	99
1¼×½×1	83
1¼×½×1¼	94
1¼×¾×¾	67
1¼×¾×1	78
1¼×¾×1¼	89
1¼×1×⅜	56
1¼×1×½	47
1¼×1×¾	65
1¼×1×1	74
1¼×1×1¼	92
1¼×1×1½	100
1¼×⅜	63
1¼×½	66
1¼×¾	71
1¼×1	80
1¼	90
1¼×1½	89
1½×½×1	91
1½×½×1½	113½
1½×¾×1¼	90
1½×¾×1½	114
1½×1×¾	81
1½×1×1	91
1½×1×1¼	94
1½×1×1½	100
1½×1¼×¾	82
1½×1¼×1	91
1½×1¼×1¼	96
1½×1¼×1½	110
1½×⅜	85
1½×½	77½
1½×¾	91½
1½×1	102
1½×1¼	102
1½	126
1½×2	131½
2×½×2	250
2×¾×2	203
2×1×2	221
2×1¼×1¼	172
2×1¼×1½	146
2×1¼×2	203
2×1½×1¼	155
2×1½×1½	169
Tees.	
2×1½×2	214
2×⅜	118
2×½	120
2×¾	107
2×1	130
2×1¼	152
2×1½	154
2	197
Side Outlet Tees.	
½	28½
¾	46
1	56½
1¼	102
Female Drop Tees.	
⅜	15½
⅜×⅜×½	20½
½×⅜×½	21
½	16
⅜×½×⅜	21
½×½×¾	27
¾×½×½	26½
½×½×⅜	16
¾	33
½×¾×½	31
¾×¾×⅜	37½
¾×¾×¾	35
½×¾×¾	34
¾×¾×½	42
1	49½
1×¾×¾	46
1×1×⅜	43
1×1×½	58
1×1×¾	63
Male and Female Drop Tees.	
½×⅜×⅜	17
⅜×⅜×⅜	14½
½	18½
½×½×⅜	18½
½×½×½	26
¾×¾×½	33
¾×¾×¾	36
Male and Female Drop Tees.	
1×¾×¾	44
1×1×¾	37
¾ with 2½" drop	25½
Male and Female Extension Pieces.	
⅜	9½
½	15
¾	22½
1	32½
R. H. Couplings.	
⅛	4½
¼	7
⅜	10½
½	17
¾	25
1	40½
1¼	53
1½	80
2	127
R. & L. Couplings.	
¼	9
⅜	13
½	17½
¾	29
1	50½
1¼	72
1½	106
2	152
Reducing Couplings.	
¼×⅛	6½
⅜×⅛	9
⅜×¼	7½
½×¼	12
½×⅜	14
¾×¼	21
¾×⅜	21
¾×½	22
1×¼	33
1×⅜	33
1×½	36

WEIGHT OF MALLEABLE-IRON FITTINGS FOR GAS-PIPE—*Continued.*

Size, Inches.	Lbs. per Hundred.	Size, Inches.	Lbs. per Hundred.	Size, Inches.	Lbs. per Hundred.
REDUCING COUPLINGS.		CROSSES.		CLOSE PATENT RETURN BENDS.	
1×3/4	31	3/4×1/2	38½	1/2	30½
1¼×3/8	54½	3/4	37½	3/4	54
1¼×1/2	[illegible]	1×1/2×3/8	37	1	88
1¼×3/4	47	1×3/4×3/8	39	1¼	152
1¼×1	53	1×3/4×1/2	50½	1½	228
1½×1/2	68	1×3/4×3/4	54½	2	333
1½×3/4	69	1×3/8	42	OPEN PATENT RETURN BENDS.	
1½×1	59	1×1/2	32	1/2	35
1½×1¼	70	1×3/4	37	3/4	104
2×3/8	85	1	59	1	134
2×1/2	90	1¼×1×3/4	73½	1¼	202½
2×3/4	102	1¼×1×1	83	1½	251
2×1	125½	1¼×3/8	65	2	[illegible]
2×1¼	91	1¼×1/2	71½	LOCK-NUTS.	
2×1½	108½	1¼×3/4	86	1/4	3
CROSSES.		1¼×1	92	3/8	5½
1/4	13½	1¼	100	1/2	7½
3/8×1/4	16	1½×1¼×1¼	92	3/4	11½
3/8	19½	1½×3/8	85	1	19
1/2×3/8×1/4	22	1½×1/2	87	1¼	27
1/2×3/8×3/8	23½	1½×3/4	108	1½	[illegible]
1/2×3/8×1/2	25	1½×1	100	2	48½
1/2×1/4	13½	1½×1¼	121	CAPS.	
1/2×3/8	[illegible]½	1½	142	1/4	5½
1/2	29½	2×1/2	101	3/8	8
3/4×3/8×1/2	34½	2×3/4	[illegible]	1/2	11½
3/4×1/2×3/8	26	2×1	118	3/4	19
3/4×1/2×1/2	36½	2×1¼	162	1	30
3/4×3/8	32	2×1½	149	1¼	40
		2	218	1½	70
				2	97

DIMENSIONS OF FLANGE PIECES.

Internal Diam of Pipe.	Thickness of Pipe.	Thickness of Flange Finished	Outside Diam of Flange	Diameter of Bolt Circle	Number of Bolts.	Diameter of Bolt-holes	Diameter of Bolts	Length of Bolts	Distance, A.	Radius, R.
Ins.	Ins.	Ins.	Ins.	Ins.		Ins.	Ins	Ins.	Ins.	Ins.
30	7/8	1¼	37½	34½	20	1	7/8	4	25	7
24	3/4	1⅛	31	28½	16	7/8	3/4	4	22	7
20	3/4	1⅛	27	24½	16	7/8	3/4	4	20	7
16	5/8	7/8	22½	20	12	7/8	3/4	3	17	6
12	9/16	7/8	18	15¾	8	3/4	5/8	2½	14	5
10	1/2	3/4	16	13¾	8	3/4	5/8	2½	12	4
8	7/16	3/4	13	11¼	8	3/4	5/8	2½	10	4
6	3/8	5/8	11	9½	4	3/4	5/8	2	8	3
4	3/8	5/8	9	9½	4	3/4	5/8	2	6	2
4	5/16	1/2	7½	5⅝	[illegible]	5/8	1/2	2	5	2

WEIGHT AND THICKNESS OF LEAD PIPE.

Caliber.	Mark.	Weight per Foot.		Thickness.	Mean Bursting Pressure.	Safe Working Pressure.
In.		Lb.	Oz.	In.	Lbs. per Sq. In.	Lbs. per Sq. In.
3/8	AAA	1	12	0.180	1968	492
3/8	AA	1	5	0.150	1627	406
3/8	A	1	2	0.130	1381	347
3/8	B	1	0	0.125	1342	336
3/8	C	0	14	0.110	1187	296
3/8	....	0	10	0.087	1065	271
7/16	....	0	9½	0.080	775	190
½	AAA	3	0	0.250	1787	446
½	....	2	8	0.225	1655	413
½	AA	2	0	0.180	1393	343
½	A	1	10	0.160	1285	321
½	B	1	3	0.125	980	245
½	C	1	0	0.100	782	195
½	D	0	9	0.065	468	117
½	....	0	10	0 070	556	139
½	....	0	12	0.090	625	156
⅝	AAA	3	8	0.230	1549	387
⅝	AA	2	12	0.210	1380	345
⅝	A	2	8	0.180	1152	288
⅝	B	2	0	0.160	987	246
⅝	C	1	7	0.117	795	198
⅝	D	1	4	0.100	708	177
¾	AAA	4	14	0.290	1462	365
¾	AA	3	8	0.225	1225	306
¾	A	3	0	0.190	1072	268
¾	B	2	3	0.150	865	216
¾	C	1	12	0.125	782	195
¾	D	1	3	0.090	505	126
1	AAA	6	0	0.300	1230	307
1	AA	4	8	0.230	910	227
1	A	4	0	0.210	857	214
1	B	3	4	0.170	745	186
1	C	2	8	0.140	562	140
1	D	2	4	0.125	518	129
1	E	2	0	0.100	475	118
1	....	1	8	0.090	325	81
1¼	AAA	6	12	0 275	962	240
1¼	AA	5	12	0.250	823	205
1¼	A	4	11	0.210	685	171
1¼	B	3	11	0.170	546	136

WEIGHT AND THICKNESS OF LEAD PIPE—*Continued.*

Caliber.	Mark.	Weight per Foot.		Thickness.	Mean Bursting Pressure.	Safe Working Pressure.
In.		Lb.	Oz.	In.	Lbs. per Sq. In.	Lbs. per Sq. In.
$1\frac{1}{4}$	C	3	0	0.135	420	105
$1\frac{1}{4}$	D	2	8	0.125	350	87
$1\frac{1}{4}$	....	2	0	0.095	322	80
$1\frac{1}{2}$	AA	8	0	0.290	742	185
$1\frac{1}{2}$	AA	7	0	0.250	700	175
$1\frac{1}{2}$	A	6	4	0.220	628	157
$1\frac{1}{2}$	B	5	0	0.180	506	126
$1\frac{1}{2}$	C	4	4	0.150	430	107
$1\frac{1}{2}$	D	3	8	0.140	315	78
$1\frac{1}{2}$	....	3	0	0.120	245	61
$1\frac{3}{4}$	B	5	0	.....	...	116
$1\frac{3}{4}$	C	4	0	.....	...	93
$1\frac{3}{4}$	D	3	10	0.125	318	79
2	AAA	10	11	0.300	611	152
2	AA	8	14	0.250	511	127
2	A	7	0	0.210	405	101
2	B	6	0	0.190	360	90
2	C	5	0	0.160	260	65
2	D	4	0	0.090	200	50

WEIGHTS OF STANDARD GAS-PIPE.

Internal Diameter in Inches.	Thickness of Shell in Inches.	Weight per Foot in Pounds.	Weight per Pipe in Pounds.	Laid Length.
2	$\frac{5}{16}$	6	48	8
3	$\frac{5}{16}$	$12\frac{1}{2}$	150	12
4	$\frac{3}{8}$	17	204	12
5	$\frac{7}{16}$	24	288	12
6	$\frac{7}{16}$	30	360	12
8	$\frac{7}{16}$	40	480	12
10	$\frac{7}{16}$	50	600	12
12	$\frac{1}{2}$	70	840	12
14	$\frac{9}{16}$	84	1000	12
16	$\frac{9}{16}$	100	1200	12
18	$\frac{11}{16}$	134	1600	12
20	$\frac{11}{16}$	150	1800	12
24	$\frac{3}{4}$	184	2200	12

APPROXIMATE SQUARE FEET OF RADIATING SURFACE OF PIPE PER LINEAL FOOT.

(On all lengths over one foot fractions less than tenths are added to or dropped.)

Length of Pipe	Diameter of Pipe.											
	¾	1	1¼	1½	2	2½	3	4	5	6	7	8
1	.275	.346	.434	.494	.622	753	916	1.175	1.455	1.739	1.996	2.257
2	0.5	0.7	0.9	1.	1 2	1 5	1.8	2.4	2.9	3.5	4.	4.5
3	0.8	1.	1 3	1.5	1 9	2 3	2 7	3.5	4.4	5.2	6	6.8
4	1.1	1 4	1.7	2.	2 5	3	3 6	4.7	5 8	7.	8.	9.
5	1.4	1.7	2.2	2.4	3.1	3 8	4.6	5.8	7.3	7.7	10.	11.3
6	1.6	2.1	2.6	2 9	3.7	4 5	5.5	7.	8 7	10.5	12.	13.5
7	1 9	2 4	3	3 4	4.4	5.3	6.4	8.2	10 2	12.1	14	15.8
8	2.2	2.8	3.5	3 9	5	6	7.3	9 4	11 6	13.9	16	18.
9	2.5	3.1	3.9	4 4	5 6	6 8	8 2	10.6	13 1	15.7	18	20.3
10	2.7	3.5	4 3	4 9	6.2	7 5	9 1	11 8	14 6	17.4	20	22.6
11	3	3.8	4 8	5 4	6 8	8 3	10.	12 9	16.	19.1	22	24.9
12	3 3	4.1	5 2	5 9	7.5	9	11.	14 1	17 4	20 9	24	27.1
13	3 6	4 5	5 6	6 4	8.1	9 8	11.9	15 3	18 9	22 6	26	29.4
14	3.8	4.8	6.1	6.9	8 7	10 5	12 8	16 5	20 3	24.3	28	31 6
15	4.1	5.2	6.5	7 4	9.3	11.3	13.7	17.6	21 8	26.1	30	33.9
16	4.4	5 5	6.9	7 9	10	12.	14.6	18 8	23 2	27.8	32	36 1
17	4.7	5 9	7 4	8 4	10.6	12 8	15 5	20	24.7	29 5	34	38 4
18	5.	6 2	7 8	8 9	11.2	13 5	16 5	21.2	26.2	31.3	36	40.6
19	5 2	6 6	8 3	9 4	11.8	14.3	17 4	22 3	27 6	33.1	38	42 9
20	5 5	6.9	8.7	9 9	12 5	15.	18.3	23.5	29.1	34.8	40	45.2
21	5 8	7 3	9 1	10 4	13	15 8	19 2	24.7	30 5	36.5	42.	47.4
22	6.	7.6	9.6	10 9	13 7	16.5	20.2	25.9	32	38.3	44.	49.7
23	6 3	8.	10.	11 3	14 3	17.3	21.1	27.	33.5	40	46	52.
24	6 6	8 3	10 4	11 9	14 9	18.	22.	28 2	34.9	41.7	48.	54.2
25	6.9	8.6	10.9	12.3	15.6	18 8	22.9	29.3	36.3	43.5	50.	56.4
26	7 1	9	11.3	12 8	16 2	19 5	23.8	30.5	37.8	45.2	52	58.6
27	7 4	9 4	11.7	13 3	16 8	20 3	24 7	31.7	39 3	47	54	61.
28	7.7	9.7	12 2	13 8	17.4	21.	25 6	32 9	40 7	48 7	56	63.2
29	8.	10.	12.6	14.3	18.	21.8	26.6	34.1	42 2	50 4	58	65.5
30	8 3	10.4	13.	14 8	18.7	22 5	27.5	35.3	43.6	52.1	60	67.7
31	8 5	10 7	13 5	15 3	19.3	23.3	28.4	36 4	45.1	53.9	62	70.
32	8.8	11.1	13.9	15 8	19 9	24 1	29.3	37 6	46.5	55.6	64	72.2
33	9.1	11 4	14.3	16 3	20 5	24.8	30.2	38.8	48	57.4	66.	74.4
34	9 4	11.7	14.7	16 8	21 2	25.6	31.1	40.	49.5	59.1	68	76.7
35	9.6	12.1	15.2	17 3	21.8	26.3	32.	41.1	50 9	60.8	70	79.
36	9 9	12.5	15 6	17 8	22.4	27.	33.	42.3	52 4	62.6	72	81.3
37	10 2	12 8	16 1	18 3	23.	27.8	33 9	43 5	53 8	64.3	74	83.5
38	10 5	13 2	16 5	18.8	23 7	28 5	34.8	44 6	55 2	66.	76	85 8
39	10.7	13.5	16.9	19 3	24 3	29 3	35.7	45.8	56 7	67.8	78	88.
40	11.	13.8	17.4	19.8	24 9	30.1	36.6	47.	58.2	69.5	80.	90.2

APPROXIMATE SQUARE FEET OF RADIATING SURFACE OF PIPE PER LINEAL FOOT—*Continued.*

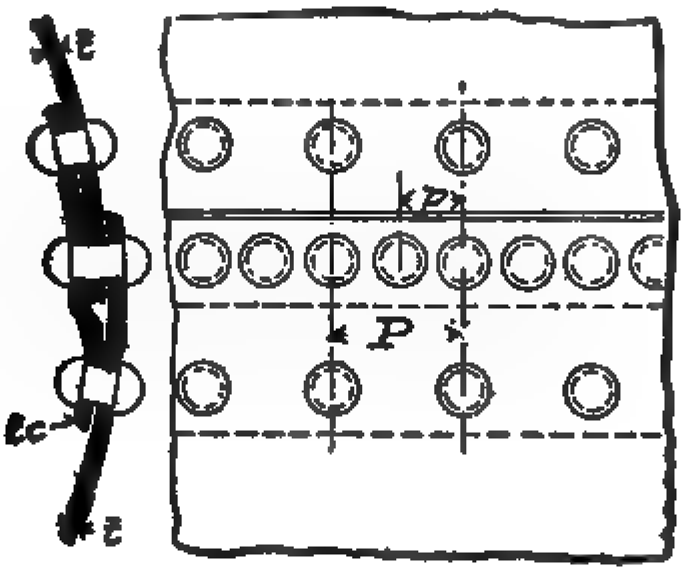
Length of Pipe.	Diameter of Pipe.											
	¾	1	1¼	1½	2	2½	3	4	5	6	7	8
41	11.3	14.2	17.8	20.3	25.5	30.8	37.6	48.2	59.6	71.3	82	92.5
42	11.5	14.5	18.2	20.8	26.1	31.6	38.5	49.4	61.1	73.	84	94.8
43	11.8	14.9	18.7	21.3	26.8	32.3	39.4	50.6	62.5	74.8	86.	97.
44	12.1	15.2	19.1	21.8	27.4	33.1	40.3	51.7	64.	76.5	88.	99.3
45	12.4	15.6	19.5	22.2	28	33.8	41.2	52.9	65.5	78.2	90	101.6
46	12.7	15.9	20	22.7	28.6	34.6	42.2	54.	67.	80.	92.	103.8
47	12.9	16.3	20.4	23.2	29.2	35.3	43.	55.2	68.4	81.7	94.	106.
48	13.2	16.6	20.8	23.7	29.9	36.1	43.9	56.4	69.8	83.5	96.	108.4
49	13.5	17.	21.3	24.2	30.5	36.8	44.8	57.6	71.2	85.1	98.	110.5
50	13.8	17.3	21.7	24.7	31.1	37.6	45.8	58.7	72.7	87.	100	112.8

SINGLE-RIVETED LAP-JOINT WITH INSIDE COVER-PLATE.

(1) Resistance to tearing between outer row of rivets $=(P-d)tT$.

(2) Resistance to tearing between inner row of rivets and shearing outer row of rivets $(P-2d)tT+\frac{\pi d^2}{4}S$.

(3) Resistance to shearing three rivets $\frac{3\pi d^2}{4}S$.



(4) Resistance to crushing in front of three rivets $=3tdC$.

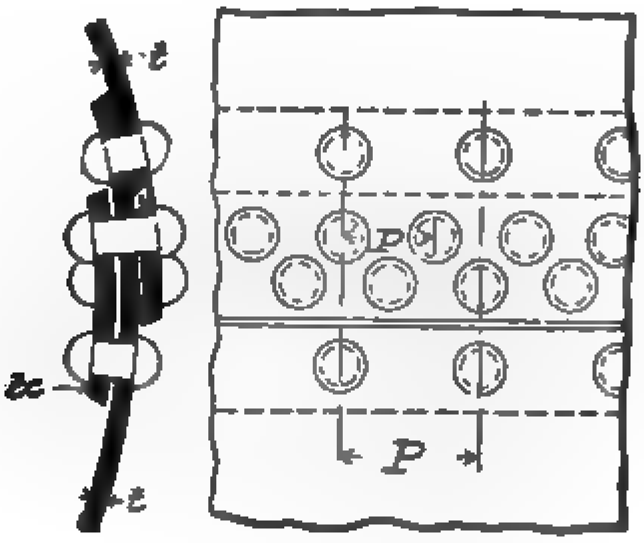
(5) Resistance to tearing at inner row of rivets and crushing in front of one rivet in outer row $=(p-2d)T+tdC$.

DOUBLE-RIVETED LAP-JOINT WITH INSIDE COVER-PLATE.

(1) Resistance to tearing at outer row of rivets $=(P-d)tT$.

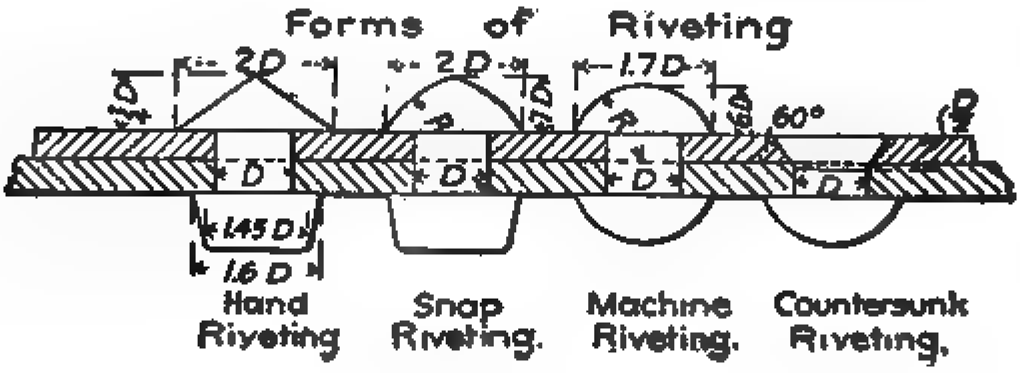
(2) Resistance to shearing four rivets $=\frac{4\pi d^2}{4}S$.

(3) Resistance to tearing at inner row and shearing outer row of rivets $=(P-1\frac{1}{2}d)tT+\frac{\pi d^2}{4}S$.



(4) Resistance to crushing in front of four rivets $=4tdC$.

(5) Resistance to tearing at inner row of rivets and crushing in front of one rivet $=(P-1\frac{1}{2}d)tT+tdC$.



TENSILE STRENGTH OF PLATE PER ONE INCH OF WIDTH.

Thickness.	Tensile Strength per Square Inch.				
	50,000	55,000	60,000	65,000	70,000
$\frac{1}{16}$	3125	3437	3750	4062	4375
$\frac{1}{8}$	6250	6875	7500	8125	8750
$\frac{3}{16}$	9375	10312	11250	12187	13125
$\frac{1}{4}$	12500	13750	15000	16250	17500
$\frac{5}{16}$	15625	17187	18750	20312	21875
$\frac{3}{8}$	18750	20625	22500	24375	26250
$\frac{7}{16}$	21875	24062	26250	28437	30625
$\frac{1}{2}$	25000	27500	30000	32500	35000
$\frac{9}{16}$	28125	30937	33750	36562	39375
$\frac{5}{8}$	31250	34375	37500	40625	43750
$\frac{11}{16}$	34375	37812	41250	44687	48125
$\frac{3}{4}$	37500	41250	45000	48750	52500
$\frac{13}{16}$	40625	44687	48750	52812	56875
$\frac{7}{8}$	43750	48125	52500	56875	61250
$\frac{15}{16}$	46875	51562	56250	60937	65625
1	50000	55000	60000	65000	70000

SHEARING STRENGTH OF RIVETS. (SINGLE SHEAR.)

Diameter of Rivet.	Area of Cross-section.	Shearing Strength per Square Inch.				
		30,000	35,000	40,000	45,000	50,000
$\frac{3}{8}$	0.1104	3312	3864	4416	4968	5520
$\frac{1}{2}$	0.1963	5889	6870	7852	8833	9815
$\frac{5}{8}$	0.3068	9204	10738	12272	13806	15340
$\frac{3}{4}$	0.4418	13254	15463	17672	19881	22090
$\frac{7}{8}$	0.6013	18039	21045	24052	27058	30065
1	0.7854	23562	27489	31416	35343	39270

CRUSHING STRENGTH OF RIVETS.

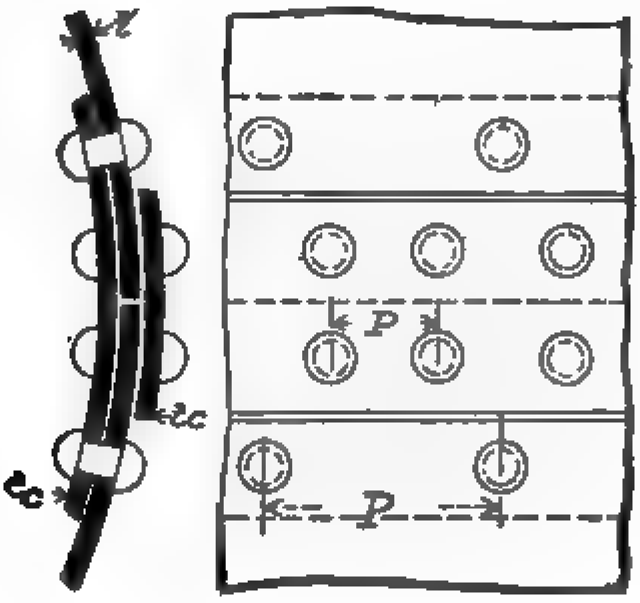
The crushing strength of rivets and plates, in joints that fail by crushing, is found by experiment to be high and irregular. In some cases it has amounted to 150,000 lbs. per square inch; in a few tests it has been less than 85,000 lbs. per square inch. A value of 95,000 lbs. may be used with safety for general calculations.

DOUBLE-RIVETED BUTT-JOINT.

(1) Resistance to tearing at outer row of rivets $=(P-d)tT$.

(2) Resistance to shearing two rivets in double shear and one in single shear $=\frac{5\pi d^2}{4}S$.

(3) Resistance to tearing at inner row of rivets and shearing one of the outer row of rivets $=(P-2d)tT+\frac{\pi d^2}{4}S$.



(4) Resistance to crushing in front of three rivets $=3tdC$.

(5) Crushing in front of two rivets and shearing one rivet $=2tdC+\frac{\pi d^2}{4}S$.

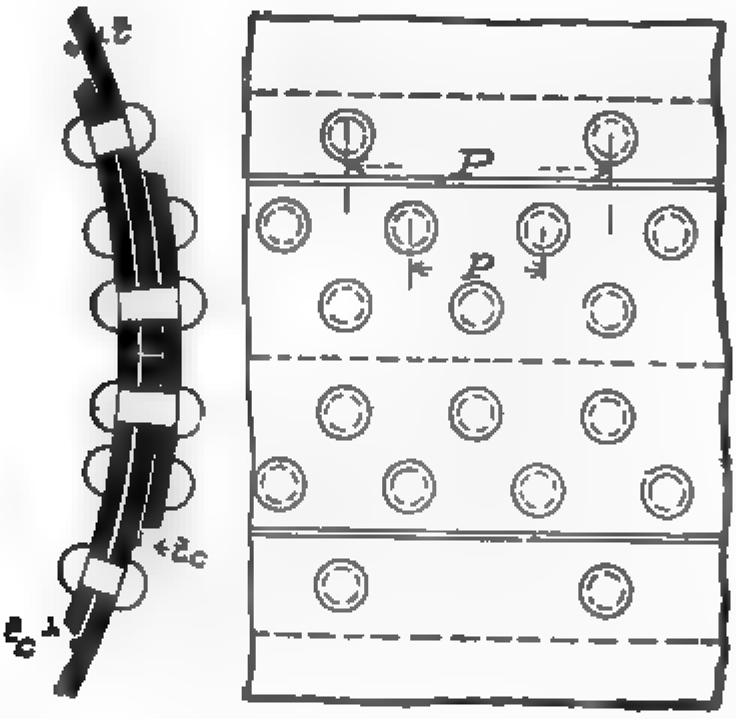
TRIPLE-RIVETED BUTT-JOINT.

(1) Resistance to tearing at outer row of rivets $=(P-d)tF$.

(2) Resistance to shearing four rivets in double shear and one in single shear $=\frac{9\pi d^2}{4}S$.

(3) Resistance to tearing at middle row of rivets and shearing one rivet $=(P-2d)tF+\frac{\pi d^2}{4}S$.

(4) Resistance to crushing in front of four rivets and shearing one rivet $= 4dtC + \frac{\pi d^2}{4}S$.



(5) Resistance to crushing in front of five rivets $4dtC + dt_cC$.

FAILURE OF RIVETED JOINTS.

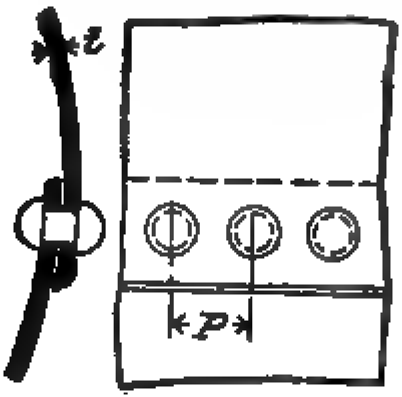
A riveted joint may fail by shearing the rivets, tearing the plate between the rivets, crushing the rivets or plate, or by a combination of two or more of the above causes.

To determine the efficiency of a riveted joint, calculate the breaking strength by the different ways in which it may fail. That method of failure giving the least result will show the actual strength of the joint. If this equals S_R, and S = tensile strength of the solid plate, then efficiency $= \frac{S_R}{S}$.

NOMENCLATURE.

d = diameter of rivets;
t = thickness of plate;
t_c = thickness of cover-plates;
p = pitch of inner row of rivets;
P = pitch of outer row of rivets;
S = shearing strength of rivets;
T = tensile strength of plate.
C = crushing strength of rivets.

SINGLE-RIVETED LAP-JOINT.

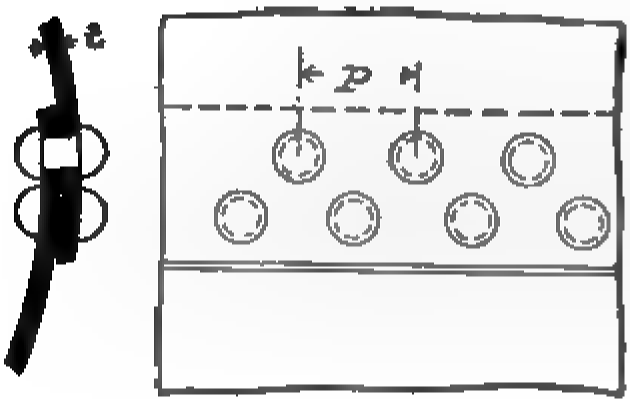


(1) Resistance to shearing one rivet $= \frac{\pi d^2}{4} S$.

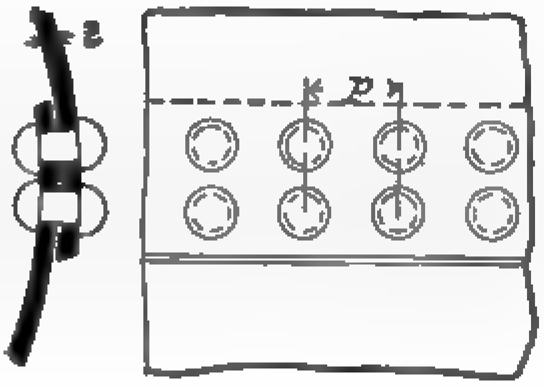
(2) " " tearing plate between rivets $= (p-d)tT$.

(3) " " crushing of rivet or plate $= dtC$.

DOUBLE-RIVETED LAP-JOINT.



Staggered Riveting



Chain Riveting.

(1) Resistance to shearing two rivets $= \frac{2\pi d^2}{4} S$.

(2) " " tearing between two rivets $= (p-d)tT$.

(3) " " crushing in front of two rivets $= 2dtC$.

MISCELLANEOUS NOTES.

To Remove Rust from Steel.—Steel which has been rusted can be cleaned by brushing with a paste compound of ½ ounce cyanide potassium, ½ ounce Castile soap, 1 ounce whiting, and water sufficient to form a paste. The steel should be washed with a solution of ½ ounce cyanide potassium in 2 ounces water.

To Preserve Steel from Rust.—1 part caoutchouc, 16 parts turpentine. Dissolve with a gentle heat, then add 8 parts of boiled oil. Mix by bringing them to the heat of boiling water;

apply to the steel with a brush, in the way of varnish. It may be removed with turpentine.

To Clean Brass.—1 part roche alum and 16 parts water. Mix. The articles to be cleaned must be made warm, then rubbed with the above mixture, and finished with fine tripoli.

Rust-joint Cement.—(Quickly setting.) 1 part sal-ammoniac in powder (by weight), 2 parts flour of sulphur, 80 parts iron borings, made to a paste with water.

(Slowly setting.) 2 parts sal-ammoniac, 1 part flour of sulphur, 200 parts iron borings. The latter cement is the best if the joint is not required for immediate use.

Red-lead Cement for Face Joints.—1 part of white lead, 1 part of red lead, mixed with linseed-oil to the proper consistency.

SPEED OF SOUND.

	Feet per Second.
In air, at zero degrees	1093
(Add 2 feet for each degree C.)	
In water	4780
In copper	11666
In iron	16822

Loads on Floors.—Floors of factories, work-shops, and warehouses should be able to carry a load of 250 lbs. to the square foot. Floors of large buildings, halls, churches, etc., should be able to carry 150 lbs. per square foot, while those of dwellings should carry 120 lbs. per square foot.

ALLOWANCES FOR WIND AND SNOW.

	Lbs. per Sq. Ft.
Weight of snow on horizontal surface	15.5
Wind pressure on surface, right angle to line of impact	24.6
In especially exposed places	31

To Test White Lead.—If pure carbonate of lead will not lose weight at 212° F., 68 grains should be entirely dissolved in 150 minims of acetic acid diluted in 1 oz. of water.

CONSUMPTION OF GAS BY GAS-ENGINES.

Consumption of gas by gas-engines ranges from 18 to 24 feet of gas per horse-power hour.

TAP DRILLS FOR "V" THREADS.

Tap.	Drill.	Tap.	Drill.	Tap.	Drill.
1/16"—60	55	1/8"—32	40	11/64"—30	29
1/16"—64	55	1/8"—36	38	11/64"—32	28
1/16"—72	55	1/8"—40	37	11/64"—36	27
No. 1 —56	54	1/8"—44	36	11/64"—40	27
1 —60	54	No. 5½ —30	38	No. 9 —24	29
1 —64	54	5½ —32	37	9 —28	28
1 —72	54	5½ —36	36	9 —30	27
1½ —56	53	5½ —40	35	9 —32	25
1½ —60	52	5½ —44	35	9 —36	24
1½ —64	52	6 —30	36	9 —40	24
1½ —72	51	6 —32	35	9½ —24	27
5/64"—56	52	6 —36	34	9½ —28	26
5/64"—60	52	6 —40	33	9½ —30	24
5/64"—64	52	9/64"—30	35	9½ —32	23
5/64"—72	51	9/64"—32	34	9½ —36	22
No. 2 —48	50	9/64"—36	33	9½ —40	22
2 —56	49	9/64"—40	32	3/16"—24	27
2 —60	49	No. 6½ —30	34	3/16"—28	26
2 —64	48	6½ —32	33	3/16"—30	24
2½ —48	47	6½ —36	32	3/16"—32	23
2½ —56	46	6½ —40	31	3/16"—36	22
2½ —60	46	7 —28	33	3/16"—40	22
3/32"—48	47	7 —30	32	No. 10 —24	27
3/32"—56	46	7 —32	32	10 —28	26
3/32"—60	46	7 —36	30	10 —30	24
No. 3 —40	47	7 —40	29	10 —32	23
3 —48	45	7½ —28	32	10 —36	22
3 —56	44	7½ —30	31	10 —40	22
3½ —40	48	7½ —32	30	10½ —24	24
3½ —48	46	7½ —36	29	10½ —28	23
3½ —56	45	7½ —40	29	10½ —30	22
7/64"—32	45	5/32"—28	32	10½ —32	21
7/64"—36	44	5/32"—30	31	10½ —36	20
7/64"—40	43	5/32"—32	30	10½ —40	20
7/64"—44	43	5/32"—36	29	11 —24	21
7/64"—48	42	5/32"—40	29	11 —28	20
No. 4 —32	45	No. 8 —24	31	11 —30	19
4 —36	44	8 —28	30	11 —32	18
4 —40	43	8 —30	30	11 —36	17
4 —44	43	8 —32	29	11 —40	17
4½ —32	42	8 —36	28	13/64"—24	21
4½ —36	41	8 —40	28	13/64"—28	20
4½ —40	40	8½ —24	30	13/64"—30	19
4½ —44	40	8½ —28	29	13/64"—32	18
5 —30	41	8½ —30	29	13/64"—36	17
5 —32	40	8½ —32	28	13/64"—40	17
5 —36	[illegible]	8½ —36	27	No. 11½ —24	19
5 —40	38	8½ —40	27	11½ —28	18
5 —44	37	11/64"—24	30	11½ —30	17
1/8"—30	41	11/64"—28	29	11½ —32	16

TAP DRILLS FOR "V" THREADS—*Continued.*

Tap.	Drill.	Tap.	Drill.	Tap.	Drill.
No. 11½ —36	15	No. 14 —20	9	9/32″—18	2
11½ —40	15	14 —22	9	9/32″—20	1
12 —20	18	14 —24	8	9/32″—24	1
12 —22	17	14 —28	8	9/32″—28	15/64″
12 —24	16	14 —30	7	9/32″—30	15/64″
12 —28	15	14 —32	7	No. 17 —16	4
12 —30	15	14 —36	6	17 —18	2
12 —32	14	14 —40	6	17 —20	1
12 —36	13	14½ —20	7	17 —24	1
12 —40	13	14½ —22	6	17 —28	15/64″
7/32″—20	20	14½ —24	5	17 —30	15/64″
7/32″—22	19	14½ —28	4	18 —16	2
7/32″—24	18	14½ —30	3	18 —18	1
7/32″—28	17	14½ —32	3	18 —20	15/64″
7/32″—30	16	14½ —36	3	18 —22	B
7/32″—32	16	14½ —40	2	18 —24	B
7/32″—36	15	¼″—20	7	18 —28	C
7/32″—40	15	¼″—22	6	18 —30	C
No. 12½ —20	16	¼″—24	5	19 —16	15/64″
12½ —22	16	¼″—28	4	19 —18	B
12½ —24	15	¼″—30	3	19 —20	C
12½ —28	14	¼″—32	3	19 —24	D
12½ —30	13	¼″—36	2	19 —30	¼″
12½ —32	12	¼″—40	2	5/16″—16	15/64″
12½ —36	11	No. 15 —18	8	5/16″—18	¼″
12½ —40	11	15 —20	7	5/16″—20	¼″
13 —20	14	15 —22	6	5/16″—24	F
13 —22	14	15 —24	5	5/16″—30	F
13 —24	13	15 —28	4	No. 20 —16	C
13 —28	12	15 —30	3	20 —18	¼″
13 —30	11	15½ —18	6	20 —20	F
13 —32	10	15½ —20	5	20 —22	F
13 —36	9	15½ —22	4	20 —24	G
13 —40	9	15½ —24	3	21 —16	¼″
15/64″—20	10	15½ —28	2	21 —18	F
15/64″—22	10	15½ —30	2	21 —20	G
15/64″—24	9	17/64″—18	6	21 —22	G
15/64″—28	9	17/64″—20	5	21 —24	H
15/64″—30	8	17/64″—22	4	22 —16	H
15/64″—32	8	17/64″—24	3	22 —18	J
15/64″—36	7	17/64″—28	2	22 —20	9/32″
15/64″—40	7	17/64″—30	2	22 —22	L
No. 13½ —20	10	No. 16 —16	8	22 —24	19/64″
13½ —22	10	16 —18	6	23 —16	J
13½ —24	9	16 —20	5	23 —18	9/32″
13½ —28	9	16 —22	4	23 —20	L
13½ —30	8	16 —24	3	23 —22	M
13½ —32	8	16 —28	2	23 —24	19/64″
13½ —36	7	16 —30	1	24 —14	L
13½ —40	7	9/32″—16	4	24 —16	19/64″

TAP DRILLS FOR "V" THREADS—*Continued.*

Tap.	Drill.	Tap.	Drill.	Tap.	Drill.
No. 24 —18	N	No. 28 —18	S	3/4"—12	[illegible]
24 —20	[illegible]	28 —20	[illegible]	13/16"—10	[illegible]
24 —22	O	7/16"—14	[illegible]	7/8"—9	[illegible]
24 —24	P	7/16"—16	[illegible]	7/8"—10	[illegible]
3/8"—14	M	7/16"—18	[illegible]	15/16"—9	[illegible]
3/8"—16	[illegible]	7/16"—20	[illegible]	1" — 7	[illegible]
3/8"—18	[illegible]	1/2"—12	[illegible]	1" — 8	[illegible]
3/8"—20	O	1/2"—13	[illegible]	1 1/8"— 7	[illegible]
3/8"—22	P	1/2"—14	[illegible]	1 1/8"— 8	[illegible]
3/8"—24	[illegible]	1/2"—16	[illegible]	1 1/4"— 7	[illegible]
No. 25 —14	[illegible]	1/2"—18	[illegible]	1 1/4"— 8	[illegible]
25 —16	[illegible]	1/2"—20	[illegible]	1 3/8"— 6	[illegible]
25 —18	[illegible]	9/16"—12	[illegible]	1 1/2"— 6	[illegible]
25 —20	[illegible]	9/16"—14	[illegible]	1 5/8"— 5	[illegible]
26 —14	[illegible]	5/8"—10	1/2"	1 3/4"— 5	[illegible]
26 —16	[illegible]	5/8" 11	[illegible]	1 7/8"— 4	[illegible]
26 —18	Q	5/8"—12	[illegible]	1 7/8"— 4 1/2	[illegible]
26 —20	[illegible]	11/16"—11	[illegible]	2" — 4	[illegible]
28 —14	[illegible]	11/16"—12	[illegible]	2" — 4 1/2	[illegible]
28 —16	S	3/4"—10	[illegible]	....	.....

USEFUL INFORMATION.

Water.—Doubling the diameter of a pipe increases its capacity four times. Friction of liquids in pipes increases as the square of the velocity.

The mean pressure of the atmosphere is usually estimated at 14.7 lbs. per square inch, so that with a perfect vacuum it will sustain a column of mercury 29.9 inches or a column of water 33.9 feet high at sea-level.

To find the pressure in pounds per square inch of a column of water, multiply the height of the column in feet by .434. Approximately, we say that every foot elevation is equal to 1/2 lb. pressure per square inch; this allows for ordinary friction.

To find the diameter of a pump cylinder to move a given quantity of water per minute (100 feet of piston being the standard of speed), divide the number of gallons by 4, then extract the square root, and the product will be the diameter in inches of the pump cylinder.

To find the quantity of water elevated in one minute running at 100 feet of piston speed per minute, square the diameter of the water cylinder in inches and multiply by 4. Example: Capacity of a 5-inch cylinder is desired. The square of the diameter (5 inches) is 25, which, multiplied by 4, gives 100, the number of gallons per minute (approximately).

To find the horse-power necessary to elevate water to a given height, multiply the weight of the water elevated per minute in pounds by the height in feet, and divide the product by 33,000 (an allowance should be added for water friction, and a further allowance for loss in steam cylinder, say from 20 to 30 per cent.).

The area of the steam piston, multiplied by the steam pressure, gives the total amount of pressure that can be exerted. *The area of the water piston*, multiplied by the pressure of water per square inch, gives the resistance. *A margin* must be made between the *power* and the *resistance* to *move* the pistons at the required speed—say from 20 to 40 per cent., according to speed and other conditions.

To find the capacity of a cylinder in gallons: Multiplying the area in inches by the length of stroke in inches will give the total number of cubic inches; divide this amount by 231 (which is the cubical contents of a U. S. gallon in inches), and the product is the capacity in gallons.

WEIGHT AND CAPACITY OF DIFFERENT STANDARD GALLONS OF WATER.

	Cubic Inches in a Gallon.	Weight of a Gallon in Pounds.	Gallons in a Cubic Foot.	
Imperial or English .	277.274	10.00	6.232102	Weight of a cubic foot of water, English standard, 62.321 lbs. avoirdupois
United States......	231.0	8.33111	7.480519	

Weight of crude petroleum, 6½ lbs. per U. S. gallon, 42 gallons to the barrel.

Weight of refined petroleum, 6½ lbs. per U. S. gallon, 42 gallons to the barrel.

A "miner's inch" of water is approximately equal to a supply of 12 U. S. gallons per minute.

HANDY RULE FOR FINDING (APPROXIMATELY) THE CONTENTS OF A PIPE IN GALLONS AND CUBIC FEET.

Rule. Multiply the square of the diameter of the pipe in inches by the length in yards, and divide by 10 for gallons and by 60 for cubic feet.

Example. A pipe is 6 inches diameter and 400 yards long; what is the content?

$$6^2 \times 400 \div 10 = 1440 \text{ gallons.}$$
$$6^2 \times 400 \div 60 = 240 \text{ cubic feet.}$$

CHEMICAL EQUATIONS FOR COMBUSTION IN OXYGEN.

Hydrogen, H.

$$2H_2+O_2=2H_2O.$$

Relation by volume	—	(2 vols.)	+	(1 vol.)	=	(2 vols.).	
" " weight	—	1	+	8	=	9	

Carbon monoxide, CO.

$$2CO+O_2=2CO_2.$$

Relation by volume	—	(2 vols.)	+	(1 vol.)	=	2 vols.
" " weight		7	+	4	=	11

Olefiant gas, C_2H_4.

$$C_2H_4+3O_2=2CO_2+2H_2O.$$

Relation by volume	—	(1 vol.)	+	(3 vols.)	=	(2 vols.)	+	(2 vols.).
" " weight	—	7	+	24	=	22	+	9

Marsh-gas, CH_4.

$$CH_4+2O_2=CO_2+2H_2O.$$

Relation by volume	—	(1 vol.)	+	(2 vols.)	=	(1 vol.)	+	(2 vols.).
" " weight	—	4	+	16	=	11	+	9

1 cu. ft. of hydrogen at 32° F. and 14.7 lbs. per sq. in. = .00599 lb. To find the weight of any other gas per cubic foot, multiply half its molecular weight by .00599.

CALORIFIC POWERS OF FUELS CALCULATED FROM ULTIMATE ANALYSIS.

Dulong's formula:

$$\text{Heating value in B.t.u.}=\tfrac{1}{100}\left[14{,}600\,C+62{,}000\left(H-\frac{O}{8}\right)+4050\,S\right].$$

$$\text{Heating value in calories}=\tfrac{1}{100}\left[8140\,C+34{,}400\left(H-\frac{O}{8}\right)+2250\,S\right].$$

Mahler's formula:

$$\text{Heating value, calories}=\tfrac{1}{100}\left[8140\,C+34{,}500\,H-3000(O+N)\right].$$

In the above C = carbon, H = hydrogen, O = oxygen, N = nitrogen, S = sulphur.

HEATS OF COMBUSTION OF VARIOUS SUBSTANCES IN OXYGEN.

(Favre and Silberman.)

One Part by Weight of	Burning to	Evolves	
		Kilo-calories.	B.t.u.
Hydrogen	H_2O at 0° C	34462	62032
"	H_2A at 100° C	28732	51717
Carbon (wood charcoal)	CO_2	8080	14544
"	CO	2473	4451
Carbon monoxide	CO_2	2403	4325
Marsh-gas	CO_2 and H_2O	13063	23513
Olefiant gas	CO^2 and H_2O	11858	21344

HEATS OF COMBUSTION OF GASES IN OXYGEN.

(By Julius Thompsen.)

Name.	Symbol.	Products of Combustion at 18° C (64.4° F.), Water Liquid.	Heat-units Evolved.		Kilo-calories per Cubic Meter.	B.t.u. per Cubic Foot.
			Calories per Kilogram of Gas.	B.t.u. per Pound of Gas.		
Acetylene	C_2H_2	$2CO_2 + H_2O$	11917	21421	13881	1554
Benzine	C_6H_6	$6CO_2 + 2H_2O$	10102	18183	35300	3954
Carbonic oxide	CO	CO_2	2436	4385	3055	342
Ethane	C_2H_6	$2CO_2 + 3H_2O$	12420	22356	16692	1870
Ethylene (olefiant gas)	C_2H_4	$2CO_2 + 2H_2O$	11931	21476	14967	1677
Hydrogen	H_2	H_2O	34180	61524	3062	344
Methane (marsh-gas)	CH_4	$CO_2 + 2H_2O$	13320	23976	9548	1070

WEIGHT AND VOLUME OF GASES AND AIR REQUIRED IN COMBUSTION.

Name.	Weight per Cubic Foot in Pounds at 32° F and 14.7 Pounds per Square Inch	Volume in Cubic Feet of 1 Pound of Gas at 14 7 Pounds per Square Inch		Cubic Feet Required to Burn 1 Cubic Foot of Gas.		Pounds Required to Burn 1 Pound of the Gas.		Cubic Feet Formed of	
		32° F	62° F	Oxygen.	Air.	Oxygen.	Air.	Steam	CO_2
Air	0 08073	12.39	13 12						
Carbon dioxide	0 12300	8 12	8 60						
Carb. monoxide	0 07830	12 77	13 55	0 5	2 39	0 57	2 4B	0	1
Hydrogen	0 00599	178 80	189 80	0 5	2.39	8 00	34 8	1	0
Marsh-gas	0 04470	22 37	23.73	2 0	9 60	4 00	17.4	2	1
Nitrogen	0 07830	12.77	13.55						
Olefiant gas	0 07830	12 77	13.55	3 0	14.4	3 43	14 9	2	2
Oxygen	0.08040	11.20	11.88						

Air = 20.92 per cent of oxygen.

1 lb. carbon burning to CO_2 requires 11.6 lbs. of air.
1 " " " " Co " 5.8 " " "
Liquid hydrocarbons approximate 20,000 B.t.u. per lb.
Good coal approximates 14,000 B.t.u. per lb.
2½ lbs. of dry wood = 1 lb. of coal or .4 lb. coal = 1 lb. wood.

SPECIFIC HEATS OF SUBSTANCES.

Solids and Liquids.

Glass	0.1937	Coal	0.20 to 0.24	Copper	0.0951
Cast iron	0.1298	Coke	0.203	Charcoal	0.2410
Wrought iron	0.1138	Brickwork, Masonry	0.20	Mercury	0.0333
Steel, soft	0.1165	Wood	0.46 to 0.65	Water	1.0000

PRESSURES, TEMPERATURE, AND VOLUME OF STEAM, FROM ATMOSPHERIC PRESSURE TO 140 LBS. PER SQUARE INCH.

Lbs. per Sq. In.	Temperature.	Volume.	Lbs. per Sq. In.	Temperature.	Volume.
At. pres.	212.8	1669	34	281.9	564
*1	216.2	1573	40	289.3	508
2	219.6	1488	45	295.5	470
3	222.7	1411	50	301.3	437
4	225.6	1343	55	306.4	408
5	228.5	1281	60	311.2	383
6	231.2	1225	65	315.8	362
7	233.8	1174	70	320.1	342
8	236.3	1127	75	324.3	325
9	238.7	1084	80	328.2	310
10	241.0	1044	85	332.0	295
12	245.5	973	90	335.8	282
14	249.6	911	95	339.2	271
16	253.6	857	100	342.7	259
18	257.3	810	105	345.8	251
20	260.9	767	110	349.1	240
22	264.3	729	115	352.1	233
24	267.5	569	120	355.0	224
26	270.6	664	125	357.9	218
28	273.6	635	130	360.6	210
30	276.4	610	135	363.4	205
32	279.2	586	140	366.0	198

* These are boiler pressures (above atmospheric), as shown by the steam-gage. The temperatures are Fahrenheit scale. The volumes given represent cubic inches of steam for every cubic inch of water evaporated.

FRENCH WEIGHTS.

One milligramme (0.001 of a gramme) =	0.0154	grains
	0.0000022	avoirdupois lbs.
One centigramme (0.01 of a gramme) =	0.1543	grains
	0.0000220	avoirdupois lbs.
One decigramme (0.1 of a gramme) =	1.5432	grains
	0.0002204	avoirdupois lbs.
One gramme (unit of weight) =	15.4323	grains
	0.0022046	avoirdupois lbs.
One decagramme (10 grammes) =	154.3234	grains
	0.0220462	avoirdupois lbs.
One hectogramme (100 grammes) =	1543.2348	grains
	0.2204621	avoirdupois lbs.
One kilogramme (1000 grammes) =	15432.3487	grains
	2.2046212	avoirdupois lbs.
One myriagramme (10,000 grammes) =	154323.487	grains
	22.0462124	avoirdupois lbs.
One quintal (100,000 grammes) =	1543234.87	grains
	220.462124	avoirdupois lbs.
One millier (1,000,000 grammes) =	15432348.7	grains
	2204.62124	avoirdupois lbs.
1016.0475443 kilogrammes =	15680000.0	grains
	2204.0	avoirdupois lbs.
		one long ton
0.45359265 kilogramme =	7000.0	grains
	1.0	avoirdupois lbs.
0.37324 kilogramme =	5760.0	grains
	1.0	troy pound

TENSION OF MERCURY VAPOR.

Degrees Centigrade.	Tension in Millimeters.	Degrees Centigrade.	Tension in Millimeters.	Degrees Centigrade.	Tension in Millimeters.
100	0.75	180	11.00	260	96.73
110	1.07	190	14.84	270	123.01
120	1.53	200	19.90	280	155.17
130	2.18	210	26.35	290	194.46
140	3.06	220	34.70	300	242.15
150	4.27	230	45.35	310	299.69
160	5.90	240	58.82	320	368.73
170	8.09	250	75.75	330	450.91

FRENCH MEASURE.

One millimeter (0.001 meter)	0.039370	inches
One centimeter (0.01 meter)	0.393704	"
One decimeter (0.1 meter)	3.937043	"
One meter (unit of length)	39.370432	"
One decameter (10 meters)...............	393.704320	"
One hectometer (100 meters)	3937.043196	"
One kilometer (1000 meters)	39370.431960	"
One myriameter (10,000 meters)	393704.319600	"

or 6 miles, 376 yards, 0 feet and $8\frac{5}{16}$ inches

WHITWORTH'S STANDARD SCREW-THREADS FOR BOLTS, WITH SIZES OF HEXAGONAL NUTS AND BOLT-HEADS.

Diameter of Bolt. Fractional Sizes.	Diameter of Bolt. Decimal Sizes.	Number of Threads per Inch.	Diameter at Bottom of Thread.	Distance Across Flats.	Distance Across Corners.	Thickness of Bolt-head.	Thickness of Nut.
$\frac{1}{16}$	0.0625	60	0.0411	0.212	0.2447	0.0547	$\frac{1}{16}$
$\frac{3}{32}$	0.09375	48	0.0670	0.280	0.3233	0.0820	$\frac{3}{32}$
$\frac{1}{8}$	0.125	40	0.0929	0.338	0.3902	0.1093	$\frac{1}{8}$
$\frac{5}{32}$	0.15625	32	0.1162	0.3875	0.4474	0.1367	$\frac{5}{32}$
$\frac{3}{16}$	0.1875	24	0.1341	0.448	0.5173	0.1640	$\frac{3}{16}$
$\frac{1}{4}$	0.25	20	0.1859	0.525	0.6062	0.2187	$\frac{1}{4}$
$\frac{5}{16}$	0.3125	18	0.2413	0.6014	0.6944	0.2734	$\frac{5}{16}$
$\frac{3}{8}$	0.375	16	0.2949	0.7094	0.8191	0.3281	$\frac{3}{8}$
$\frac{7}{16}$	0.4375	14	0.3460	0.8204	0.9473	0.3828	$\frac{7}{16}$
$\frac{1}{2}$	0.5	12	0.3932	0.9191	1.0612	0.4375	$\frac{1}{2}$
$\frac{9}{16}$	0.5625	12	0.4557	1.011	1.1674	0.4921	$\frac{9}{16}$
$\frac{5}{8}$	0.625	11	0.5085	1.101	1.2713	0.5468	$\frac{5}{8}$
$\frac{11}{16}$	0.6875	11	0.5710	1.2011	1.3869	0.6015	$\frac{11}{16}$
$\frac{3}{4}$	0.75	10	0.6219	1.3012	1.5024	0.6562	$\frac{3}{4}$
$\frac{13}{16}$	0.8125	10	0.6844	1.39	1.6050	0.7109	$\frac{13}{16}$
$\frac{7}{8}$	0.875	9	0.7327	1.4788	1.7075	0.7656	$\frac{7}{8}$
$\frac{15}{16}$	0.9375	9	0.7952	1.5745	1.8180	0.8203	$\frac{15}{16}$
1	1.0	8	0.8399	1.6701	1.9284	0.875	1
$1\frac{1}{8}$	1.125	7	0.9420	1.8605	2.1483	0.9843	$1\frac{1}{8}$
$1\frac{1}{4}$	1.25	7	1.0670	2.0483	2.3651	1.0937	$1\frac{1}{4}$
$1\frac{3}{8}$	1.375	6	1.1615	2.2146	2.5571	1.2031	$1\frac{3}{8}$
$1\frac{1}{2}$	1.5	6	1.2865	2.4134	2.7867	1.3125	$1\frac{1}{2}$
$1\frac{5}{8}$	1.625	5	1.3688	2.5763	2.9748	1.4218	$1\frac{5}{8}$
$1\frac{3}{4}$	1.75	5	1.4938	2.7578	3.1844	1.5312	$1\frac{3}{4}$
$1\frac{7}{8}$	1.875	4.5	1.5904	3.0183	3.4852	1.6406	$1\frac{7}{8}$
2	2.0	4.5	1.7154	3.1491	3.6362	1.75	2
$2\frac{1}{8}$	2.125	4.5	1.8404	3.337	3.8532	1.8593	$2\frac{1}{8}$
$2\frac{1}{4}$	2.25	4	1.9298	3.546	4.0945	1.9687	$2\frac{1}{4}$
$2\frac{3}{8}$	2.375	4	2.0548	3.75	4.3301	2.0781	$2\frac{3}{8}$
$2\frac{1}{2}$	2.5	4	2.1798	3.894	4.4964	2.1875	$2\frac{1}{2}$
$2\frac{5}{8}$	2.625	4	2.3048	4.049	4.6753	2.2968	$2\frac{5}{8}$
$2\frac{3}{4}$	2.75	3.5	2.3840	4.181	4.8278	2.4062	$2\frac{3}{4}$
$2\frac{7}{8}$	2.875	3.5	2.5090	4.3456	5.0178	2.5156	$2\frac{7}{8}$
3	3.0	3.5	2.6340	4.531	5.2319	2.625	3
$3\frac{1}{8}$	3.125	3.5	2.7590	4.69	5.4155	2.734	$3\frac{1}{8}$
$3\frac{1}{4}$	3.25	3.25	2.8559	4.85	5.6002	2.843	$3\frac{1}{4}$
$3\frac{3}{8}$	3.375	3.25	2.9809	5.01	5.7850	2.953	$3\frac{3}{8}$
$3\frac{1}{2}$	3.5	3.25	3.1059	5.157	5.9755	3.062	$3\frac{1}{2}$

WHITWORTH'S STANDARD SCREW-THREADS FOR BOLTS, WITH SIZES OF HEXAGONAL NUTS AND BOLT-HEADS—*Continued.*

Diameter of Bolt.		Number of Threads per Inch.	Diameter at Bottom of Thread.	Distance Across Flats.	Distance Across Corners.	Thickness of Bolt-head.	Thickness of Nut.
Fractional Sizes.	Decimal Sizes.						
$3\frac{5}{8}$	3.625	3.25	3.2309	5.362	6.1915	3.171	$3\frac{5}{8}$
$3\frac{3}{4}$	3.75	3	3.3231	5.55	6.4085	3.281	$3\frac{3}{4}$
$3\frac{7}{8}$	3.875	3	3.4481	5.75	6.6395	3.39	$3\frac{7}{8}$
4	4.0	3	3.5731	5.95	6.8704	3.5	4
$4\frac{1}{8}$	4.125	3	3.6981	6.162	7.1152	3.609	$4\frac{1}{8}$
$4\frac{1}{4}$	4.25	2.875	3.8045	6.375	7.3612	3.718	$4\frac{1}{4}$
$4\frac{3}{8}$	4.375	2.875	3.9295	6.6	7.6210	3.828	$4\frac{3}{8}$
$4\frac{1}{2}$	4.5	2.875	4.0545	6.825	7.8819	3.937	$4\frac{1}{2}$
$4\frac{5}{8}$	4.625	2.875	4.1795	7.0625	8.1550	4.046	$4\frac{5}{8}$
$4\frac{3}{4}$	4.75	2.75	4.2843	7.3	8.4293	4.156	$4\frac{3}{4}$
$4\frac{7}{8}$	4.875	2.75	4.4093	7.55	8.7179	4.265	$4\frac{7}{8}$
5	5.0	2.75	4.5343	7.8	9.0066	4.375	5
$5\frac{1}{8}$	5.125	2.75	4.6593	8.065	9.3126	4.484	$5\frac{1}{8}$
$5\frac{1}{4}$	5.25	2.625	4.7621	8.35	9.6417	4.593	$5\frac{1}{4}$
$5\frac{3}{8}$	5.375	2.625	4.8871	8.6	9.9304	4.703	$5\frac{3}{8}$
$5\frac{1}{2}$	5.5	2.625	5.0121	8.85	10.2190	4.812	$5\frac{1}{2}$
$5\frac{5}{8}$	5.625	2.625	5.1371	9.15	10.5655	4.921	$5\frac{5}{8}$
$5\frac{3}{4}$	5.75	2.5	5.2377	9.45	10.9119	5.031	$5\frac{3}{4}$
$5\frac{7}{8}$	5.875	2.5	5.3627	9.75	11.2583	5.140	$5\frac{7}{8}$
6	6.0	2.5	5.4877	10.0	11.5470	5.25	6

The tables given below will be found useful in heat calculations, and although not minutely accurate are sufficiently so for practical work. The British thermal unit (B.t.u.) is used, and the heat-energies given are calculated upon the assumption of 62° F. as the initial temperature, and the reduction of the temperature of the products of combustion to the same point as the standard for the computation of all heat-energies:

Air by weight contains 23 parts O, 77 parts N.

Air by volume contains 21 parts O, 79 parts N.

Air consumed in combustion:

1 pound C burned to CO consumes 1.33 pounds O, with 4.46 N, making 5.79 air.

1 pound C burned to CO_2 consumes 2.667 pounds O, with 8.927 N, making 11.594 air.

Heat-units Developed in Burning.	For 1 Lb. of Combustible, B.t.u.	For 1 Cu. Ft. of Combustible, B.t.u.
C to CO	4,400	
C to CO_2	14,500	
CO to CO_2	4,325	319
H to H_2O	62,000	327
CH_4 to CO_2 and H_2O	23,500	1007
C_2H_4 to CO_2 and H_2O	21,400	1593

Of course hydrogen is usually only burned to steam, and the energy in this case at 62° initial and 212° final temperature is 52,000 heat-units, or, making both temperatures 212°, about 53,000 heat-units. Many writers use this standard for hydrogen in their computations; but in all theoretical calculations hydrogen should be given credit for the energy developed when the products of combustion are reduced to the standard temperature and the losses computed in its utilization from that standard.

Number of cubic feet in one pound of the following gases at 62° F. and atmospheric pressure:

Air	13.14	cubic feet per pound.
N	13.50	" " " "
O	11.88	" " " "
H	189.70	" " " "
CO	13.55	" " " "
CO_2	8.60	" " " "
CH_4	23.32	" " " "
C_2H_4	13.46	" " " "
Specific heat of hydrogen	3.4	
" " " all other gases may be taken at	0.25	

The terms "heat-units" and "specific heat" are not well understood by many people, but the following definitions by a well-known authority will make them clear:

Specific heat is that quantity of heat required to raise one pound of any substance one degree compared with that required to raise the temperature of an equal weight of water one degree. In other words, in writing down the specific heat of any substance we do it in comparison with water. That is to say, water is the unit or standard. If it takes three and four-tenths times as much heat to raise one pound of hydrogen one degree as to raise one pound of water one degree, we say the specific heat of hydrogen is 3.4. Now the same quantity of heat that will raise a pound of water one degree will raise about ten pounds of iron one degree, so we say the specific heat of iron is 0.10, or, to be exact, 0.1098.

Wood and Coal Fuel.—The American Society of Mechanical Engineers in their rules for boiler tests allow 1 lb. of wood=0.4 lb. of coal, or 2½ lbs. of wood=1 lb. of coal. Other authorities estimate 2¼ lbs. of dry wood=1 lb. of good coal. One pound of any wood is practically equivalent to 1 lb. of any other kind of wood equally dry.

	Lbs.		Lbs. Coal.
1 cord of hickory or hard maple weighs............	4500	=	2000
1 cord of white oak weighs.......................	3850	=	1711
1 cord of beech, red oak, or black oak weighs......	3250	=	1445
1 cord of poplar, chestnut, or elm weighs..........	2350	=	1044
1 cord of average pine weighs....................	2000	=	890

COMPARISON OF THERMOMETER SCALES.

Centigrade.	Reaumur.	Fahrenheit.	Centigrade.	Reaumur.	Fahrenheit.	Centigrade.	Reaumur.	Fahrenheit.
−30	−24.0	−22.0	14	11.2	57.2	58	46.4	136.4
−28	−22.4	−18.4	16	12.8	60.8	60	48.0	140.0
−26	−20.8	−14.8	18	14.4	64.4	62	49.6	143.6
−24	−19.2	−11.2	20	16.0	68.0	64	51.2	147.2
−22	−17.6	− 7.6	22	17.6	71.6	66	52.8	150.8
−20	−16.0	− 4.0	24	19.2	75.2	68	54.4	154.4
−18	−14.4	− 0.4	26	20.8	78.8	70	56.0	158.0
−16	−12.8	3.2	28	22.4	82.4	72	57.6	161.6
−14	−11.2	6.8	30	24.0	86.0	74	59.2	165.2
−12	− 9.6	10.4	32	25.6	89.6	76	60.8	168.8
−10	− 8.0	14.0	34	27.2	93.2	78	62.4	172.4
− 8	− 6.4	17.6	36	28.8	96.8	80	64.0	176.0
− 6	− 4.8	21.2	38	30.4	100.4	82	65.6	179.6
− 4	− 3.2	24.8	40	32.0	104.0	84	67.2	183.2
− 2	− 1.6	28.4	42	33.6	107.6	86	68.8	186.8
0	0.0	32.0	44	35.2	111.2	88	70.4	190.4
2	1.6	35.6	46	36.8	114.8	90	72.0	194.0
4	3.2	39.2	48	38.4	118.4	92	73.6	197.6
6	4.8	42.8	50	40.0	122.0	94	75.2	201.2
8	6.4	46.4	52	41.6	125.6	96	76.8	204.8
10	8.0	50.0	54	43.2	129.2	98	78.4	208.4
12	9.6	53.6	56	44.8	132.8	100	80.0	212.0

MULTIPLIERS FOR FINDING THE EQUIVALENT RATE OF EVAPORATION OF WATER FROM AND AT 212° F., FOR GIVEN PRESSURES OF STEAM AND TEMPERATURES OF FEED-WATER.

Temperature of Feed-water, ° Fahr.	Boiler Pressures in Pounds per Square Inch above the Atmosphere.						
	0	5	10	15	20	25	30
32	1.187	1.192	1.195	1.199	1.201	1.204	1.206
35	1.184	1.189	1.192	1.196	1.198	1.201	1.203
40	1.179	1.184	1.187	1.191	1.193	1.196	1.198
45	1.173	1.178	1.181	1.185	1.187	1.190	1.192
50	1.168	1.173	1.177	1.180	1.182	1.185	1.187
55	1.163	1.168	1.171	1.175	1.177	1.180	1.182
60	1.158	1.163	1.166	1.170	1.172	1.175	1.177
65	1.153	1.158	1.161	1.165	1.167	1.170	1.172
70	1.148	1.153	1.156	1.160	1.162	1.165	1.167
75	1.143	1.148	1.151	1.155	1.157	1.160	1.162
80	1.137	1.143	1.146	1.149	1.151	1.154	1.156
85	1.132	1.137	1.140	1.144	1.146	1.149	1.151
90	1.127	1.132	1.135	1.139	1.141	1.144	1.146
95	1.122	1.127	1.130	1.134	1.136	1.139	1.141
100	1.117	1.122	1.125	1.129	1.131	1.134	1.136
105	1.111	1.117	1.120	1.123	1.125	1.128	1.130
110	1.106	1.111	1.114	1.118	1.120	1.123	1.125
115	1.101	1.106	1.109	1.113	1.115	1.118	1.120
120	1.096	1.101	1.104	1.108	1.101	1.113	1.115
125	1.091	1.096	1.099	1.103	1.105	1.108	1.110
130	1.085	1.091	1.094	1.097	1.099	1.102	1.104
135	1.080	1.085	1.088	1.092	1.094	1.097	1.099
140	1.075	1.080	1.083	1.087	1.089	1.092	1.094
145	1.070	1.075	1.078	1.082	1.084	1.087	1.089
150	1.065	1.070	1.073	1.077	1.079	1.082	1.084
155	1.059	1.065	1.068	1.071	1.073	1.076	1.078
160	1.054	1.059	1.062	1.066	1.068	1.071	1.073
165	1.049	1.054	1.057	1.061	1.063	1.066	1.068
170	1.044	1.049	1.052	1.056	1.058	1.061	1.063
175	1.039	1.044	1.047	1.051	1.053	1.056	1.058
180	1.033	1.039	1.042	1.045	1.047	1.050	1.052
185	1.028	1.033	1.036	1.040	1.042	1.045	1.047
190	1.023	1.028	1.031	1.035	1.037	1.040	1.042
195	1.018	1.023	1.025	1.030	1.032	1.035	1.037
200	1.013	1.018	1.021	1.025	1.027	1.030	1.032
205	1.008	1.013	1.015	1.020	1.022	1.025	1.027
210	1.008	1.008	1.011	1.015	1.017	1.020	1.022
212	1.002	1.002					

MULTIPLIERS FOR FINDING THE EQUIVALENT RATE OF EVAPORATION OF WATER FROM AND AT 212° F., FOR GIVEN PRESSURES OF STEAM AND TEMPERATURES OF FEED-WATER—*Continued.*

Temperature of Feed-Water, ° Fahr.	Boiler Pressures in Pounds per Square Inch above the Atmosphere.						
	35	40	45	50	60	70	80
32	1.209	1.211	1.212	1.214	1.217	1.219	1.222
35	1.206	1.208	1.209	1.211	1.214	1.216	1.219
40	1.201	1.203	1.204	1.206	1.209	1.211	1.214
45	1.195	1.197	1.198	1.200	1.203	1.205	1.208
50	1.190	1.192	1.193	1.195	1.198	1.200	1.203
55	1.185	1.187	1.188	1.190	1.193	1.195	1.198
60	1.180	1.182	1.183	1.185	1.188	1.190	1.193
65	1.175	1.177	1.178	1.180	1.183	1.185	1.188
70	1.170	1.172	1.173	1.175	1.178	1.180	1.183
75	1.165	1.167	1.168	1.170	1.173	1.175	1.178
80	1.159	1.161	1.162	1.164	1.167	1.169	1.172
85	1.154	1.156	1.157	1.159	1.162	1.164	1.167
90	1.149	1.151	1.152	1.154	1.157	1.159	1.162
95	1.144	1.146	1.147	1.149	1.152	1.154	1.157
100	1.139	1.141	1.142	1.144	1.147	1.149	1.152
105	1.133	1.135	1.136	1.138	1.141	1.143	1.146
110	1.128	1.130	1.131	1.133	1.136	1.138	1.141
115	1.123	1.125	1.126	1.128	1.131	1.133	1.136
120	1.118	1.120	1.121	1.123	1.126	1.128	1.131
125	1.113	1.115	1.116	1.118	1.121	1.123	1.126
130	1.107	1.109	1.110	1.112	1.115	1.117	1.120
135	1.102	1.104	1.105	1.107	1.110	1.112	1.115
140	1.097	1.099	1.100	1.102	1.105	1.107	1.110
145	1.092	1.094	1.095	1.097	1.100	1.102	1.105
150	1.078	1.089	1.090	1.092	1.095	1.097	1.100
155	1.081	1.083	1.084	1.086	1.089	1.091	1.094
160	1.076	1.078	1.079	1.081	1.084	1.086	1.089
165	1.071	1.073	1.074	1.076	1.079	1.081	1.084
170	1.066	1.068	1.069	1.071	1.074	1.076	1.079
175	1.061	1 063	1.064	1.066	1.069	1.071	1.074
180	1.055	1 057	1.058	1.060	1.063	1.065	1.068
185	1.050	1.052	1.053	1.055	1.058	1.060	1.063
190	1.045	1.047	1.048	1.050	1.053	1.055	1.058
195	1.040	1.042	1.043	1.045	1.048	1.050	1.053
200	1.035	1.037	1.038	1.040	1.043	1.045	1.048
205	1.030	1.032	1.033	1.035	1.038	1.040	1.043
210	1.025	1.027	1.028	1.030	1.033	1.035	1.038

MULTIPLIERS FOR FINDING THE EQUIVALENT RATE OF EVAPORATION OF WATER FROM AND AT 212° F., FOR GIVEN PRESSURES OF STEAM AND TEMPERATURES OF FEED-WATER—*Continued.*

Temperature of Feed-water, ° Fahr.	Boiler Pressures in Pounds per Square Inch above the Atmosphere.						
	90	100	120	140	160	180	200
32	1.224	1.227	1.231	1.234	1.237	1.239	1.241
35	1.221	1.224	1.228	1.231	1.234	1.236	1.238
40	1.216	1.219	1.223	1.226	1.229	1.231	1.233
45	1.210	1.213	1.217	1.220	1.223	1.225	1.227
50	1.205	1.208	1.212	1.215	1.218	1.220	1.222
55	1.200	1.203	1.207	1.210	1.213	1.215	1.217
60	1.195	1.198	1.202	1.205	1.208	1.210	1.212
65	1.190	1.193	1.197	1.200	1.203	1.205	1.207
70	1.185	1.188	1.192	1.195	1.198	1.200	1.202
75	1.180	1.183	1.187	1.190	1.193	1.195	1.197
80	1.174	1.177	1.181	1.184	1.187	1.189	1.191
85	1.169	1.172	1.176	1.179	1.182	1.184	1.186
90	1.164	1.167	1.171	1.174	1.177	1.179	1.181
95	1.159	1.162	1.166	1.169	1.172	1.174	1.176
100	1.154	1.157	1.161	1.164	1.167	1.169	1.171
105	1.148	1.151	1.155	1.158	1.161	1.163	1.165
110	1.143	1.146	1.150	1.153	1.156	1.158	1.160
115	1.138	1.141	1.145	1.148	1.151	1.153	1.155
120	1.133	1.136	1.140	1.143	1.146	1.148	1.150
125	1.128	1.131	1.135	1.138	1.141	1.143	1.145
130	1.122	1.125	1.129	1.132	1.135	1.137	1.139
135	1.117	1.120	1.124	1.127	1.130	1.132	1.134
140	1.112	1.115	1.119	1.122	1.125	1.127	1.129
145	1.107	1.110	1.114	1.117	1.120	1.122	1.124
150	1.102	1.105	1.109	1.112	1.115	1.117	1.119
155	1.096	1.099	1.103	1.106	1.109	1.111	1.113
160	1.091	1.094	1.098	1.101	1.104	1.106	1.108
165	1.086	1.089	1.093	1.096	1.099	1.101	1.103
107	1.081	1.084	1.088	1.091	1.094	1.096	1.098
175	1.076	1.079	1.083	1.086	1.089	1.091	1.093
180	1.070	1.073	1.077	1.080	1.083	1.085	1.087
185	1.065	1.068	1.072	1.075	1.078	1.080	1.082
190	1.060	1.063	1.067	1.070	1.073	1.075	1.077
195	1.055	1.058	1.062	1.065	1.068	1.070	1.072
200	1.050	1.053	1.057	1.060	1.063	1.065	1.067
205	1.045	1.048	1.052	1.055	1.058	1.060	1.062
210	1.040	1.043	1.047	1.050	1.053	1.550	1.057

STANDARD SPECIFICATIONS FOR CAST-IRON PIPE AND SPECIAL CASTINGS.

DESCRIPTION OF PIPES.

SECTION 1. The pipes shall be made with hub and spigot joints, and shall accurately conform to the dimensions given in Tables Nos. 1 and 2. They shall be straight and shall be true circles in section, with their inner and outer surfaces concentric, and shall be of the specified dimensions in outside diameter. They shall be at least 12 feet in length, exclusive of socket. For pipes of each size from 4-inch to 24-inch, inclusive, there shall be two standards of outside diameter, and for pipes from 30-inch to 60-inch, inclusive, there shall be four standards of outside diameter, as shown by Table No. 2.

All pipes having the same outside diameter shall have the same inside diameter at both ends. The inside diameter of the lighter pipes of each standard outside diameter shall be gradually increased for a distance of about 6 inches from each end of the pipe so as to obtain the required standard thickness and weight for each size and class of pipe.

Pipes whose standard thickness and weight are intermediate between the classes in Table No. 2 shall be made of the same outside diameter as the next heavier class. Pipes whose standard thickness and weight are less than shown by Table No. 2 shall be made of the same outside diameter as the Class A pipes, and pipes whose thickness and weight are more than shown by Table No. 2 shall be made of the same outside diameter as the Class D pipes.

For pipes 4-inch to 12-inch, inclusive, one class of special castings shall be furnished, made from Class D pattern. Those having spigot ends shall have outside diameters of spigot ends midway between the two standards of outside diameter as shown by Table No. 2, and shall be tapered back for a distance of 6 inches. For pipes from 14-inch to 24-inch, inclusive, two classes of special castings shall be furnished, Class B special castings with Classes A and B pipes, and Class D special castings with Classes C and D pipes, the former to be stamped "AB" and the latter to be stamped "CD". For pipes 30-inch to 60-inch, inclusive, four classes of special castings shall be furnished, one for each class of pipe, and shall be stamped with the letter of the class to which they belong.

ALLOWABLE VARIATION IN DIAMETER OF PIPES AND SOCKETS.

SECTION 2. Especial care shall be taken to have the sockets of the required size. The sockets and spigots will be tested by circular gages, and no pipe will be received which is defective in joint room from any cause. The diameters of the sockets and the outside diameters of the bead ends of the pipes shall not vary from the standard dimensions by more than .06 of an inch for pipes 16 inches or less in diameter; .08 of an inch for 18-inch, 20-inch, and 24-inch pipes; .10 of an inch for 30-inch, 36-inch, and 42-inch pipes; .12 of an inch for 48-inch, and .15 of an inch for 54-inch and 60-inch pipes.

ALLOWABLE VARIATION IN THICKNESS.

SECTION 3. For pipes whose standard thickness is less than 1 inch the thickness of metal in the body of the pipe shall not be more than .08 of an inch less than the standard thickness, and for pipes whose standard thickness is 1 inch or more, the variation shall not exceed .10 of an inch, except that for spaces not exceeding 8 inches in length in any direction, variations from the standard thickness of .02 of an inch in excess of the allowance above given shall be permitted.

For special castings of standard patterns a variation of 50 per cent. greater than allowed for straight pipe shall be permitted.

DEFECTIVE SPIGOTS MAY BE CUT.

SECTION 4. Defective spigot ends on pipes 12 inches or more in diameter may be cut off in a lathe and a half-round wrought-iron band shrunk into a groove cut in the end of the pipe. Not more than 12 per cent. of the total number of accepted pipes of each size shall be cut and banded, and no pipe shall be banded which is less than 11 feet in length, exclusive of the socket.

In case the length of a pipe differs from 12 feet, the standard weight of the pipe given in Table No. 2 shall be modified in accordance therewith.

SPECIAL CASTINGS.

SECTION 5. All special castings shall be made in accordance with the cuts and the dimensions given in the table forming a part of these specifications.

The diameters of the sockets and the external diameters of

the bead ends of the special castings shall not vary from the standard dimensions by more than .12 of an inch for castings 16 inches or less in diameter; .15 of an inch for 18-inch, 20-inch, and 24-inch; .20 of an inch for 30-inch, 36-inch, and 42-inch, and .24 of an inch for 48-inch, 54-inch, and 60-inch. These variations apply only to special castings made from standard patterns.

The flanges on all manhole castings and manhole covers shall be faced true and smooth, and drilled to receive the bolts of the sizes given in the tables. The manufacturer shall furnish and deliver all bolts for bolting on the manhole covers, the bolts to be of the sizes shown on plans and made of the best quality of mild steel, with hexagonal heads and nuts and sound, well-fitting threads.

MARKINGS.

SECTION 6. Every pipe and special casting shall have distinctly cast upon it the initials of the maker's name. When cast especially to order, each pipe and special casting larger than 4-inch may also have cast upon it figures showing the year in which it was cast and a number signifying the order in point of time in which it was cast, the figures denoting the year being above and the number below, thus:

1901	1901	1901
1	2	3

etc., also any initials, not exceeding four, which may be required by the purchaser. The letters and figures shall be cast on the outside and shall be not less than 2 inches in length and $\frac{1}{8}$ of an inch in relief for pipes 8 inches in diameter and larger. For smaller sizes of pipes the letters may be 1 inch in length. The weight and the class letter shall be conspicuously painted in white on the inside of each pipe and special casting after the coating has become hard.

ALLOWABLE PERCENTAGE OF VARIATION IN WEIGHT.

SECTION 7. No pipe shall be accepted the weight of which shall be less than the standard weight by more than 5 per cent. for pipes 16 inches or less in diameter, and 4 per cent. for pipes more than 16 inches in diameter, and no excess above the standard weight of more than the given percentages for the several sizes shall be paid for. The total weight to be paid for shall not exceed for each size and class of pipe received the sum of the standard weights of the same number of pieces of the given size and class by more than 2 per cent.

No special casting shall be accepted the weight of which shall be less than the standard weight by more than 10 per cent. for pipes 12 inches or less in diameter, and 8 per cent. for larger sizes, except that curves, Y pieces, and breeches pipe may be 12 per cent. below the standard weight, and no excess above the standard weight of more than the above percentages for the several sizes will be paid for. These variations apply only to castings made from the standard patterns.

QUALITY OF IRON.

SECTION 8. All pipes and special castings shall be made of cast iron of good quality, and of such character as shall make the metal of the castings strong, tough, and of even grain, and soft enough to satisfactorily admit of drilling and cutting. The metal shall be made without any admixture of cinder iron or other inferior metal, and shall be remelted in a cupola or air-furnace.

TESTS OF MATERIAL.

SECTION 9. Specimen bars of the metal used, each being 26 inches long by 2 inches wide and 1 inch thick, shall be made without charge as often as the engineer may direct, and, in default of definite instructions, the contractor shall make and test at least one bar from each heat or run of metal. The bars, when placed flatwise upon supports 24 inches apart and loaded in the center, shall for pipes 12 inches or less in diameter support a load of 1900 pounds and show a deflection of not less than .30 of an inch before breaking, and for pipes of sizes larger than 12 inches shall support a load of 2000 pounds and show a deflection of not less than .32 of an inch. The contractor shall have the right to make and break three bars from each heat or run of metal, and the test shall be based upon the average results of the three bars. Should the dimensions of the bars differ from those above given, a proper allowance therefor shall be made in the results of the tests.

CASTING OF PIPES.

SECTION 10. The straight pipes shall be cast in dry sand molds in a vertical position. Pipes 16 inches or less in diameter shall be cast with the hub end up or down, as specified in the proposal. Pipes 18 inches or more in diameter shall be cast with the hub end down.

The pipes shall not be stripped or taken from the pit while showing color of heat, but shall be left in the flasks for a sufficient length of time to prevent unequal contraction by subsequent exposure.

QUALITY OF CASTINGS.

SECTION 11. The pipes and special castings shall be smooth, free from scales, lumps, blisters, sand holes, and defects of every nature which unfit them for the use for which they are intended. No plugging or filling will be allowed.

CLEANING AND INSPECTION.

SECTION 12. All pipes and special castings shall be thoroughly cleaned and subjected to a careful hammer inspection. No casting shall be coated unless entirely clean and free from rust, and approved in these respects by the engineer immediately before being dipped.

COATING.

SECTION 13. Every pipe and special casting shall be coated inside and out with coal-tar pitch varnish. The varnish shall be made from coal-tar. To this material sufficient oil shall be added to make a smooth coating, tough and tenacious when cold, and not brittle nor with any tendency to scale off.

Each casting shall be heated to a temperature of 300 degrees Fahrenheit immediately before it is dipped, and shall possess less than this temperature at the time it is put in the vat. The ovens in which the pipes are heated shall be so arranged that all portions of the pipe shall be heated to an even temperature. Each casting shall remain in the bath at least five minutes.

The varnish shall be heated to a temperature of 300 degrees Fahrenheit (or less if the engineer shall so order), and shall be maintained at this temperature during the time the casting is immersed.

Fresh pitch and oil shall be added when necessary to keep the mixture at the proper consistency, and the vat shall be emptied of its contents and refilled with fresh pitch when deemed necessary by the engineer. After being coated the pipes shall be carefully drained of the surplus varnish. Any pipe or special casting that is to be recoated shall first be thoroughly scraped and cleaned.

HYDROSTATIC TEST.

SECTION 14. When the coating has become hard, the straight pipes shall be subjected to a proof by hydrostatic pressure and, if required by the engineer, they shall also be subjected to a hammer test under this pressure.

The pressures to which the different sizes and classes of pipes shall be subjected are as follows:

	20-inch Diameter and Larger, Lbs. per Sq. In.	Less than 20-inch Diameter Lbs. per Sq. In.
Class A pipe.	150	300
Class B pipe.	200	300
Class C pipe.	250	300
Class D pipe.	300	300

WEIGHING.

SECTION 15. The pipes and special castings shall be weighed for payment under the supervision of the engineer after the application of the coal-tar pitch varnish. If desired by the engineer, the pipes and special castings shall be weighed after their delivery, and the weights so ascertained shall be used in the final settlement, provided such weighing is done by a legalized weighmaster. Bids shall be submitted and a final settlement made up on the basis of a ton of 2000 pounds.

CONTRACTOR TO FURNISH MEN AND MATERIALS.

SECTION 16. The contractor shall provide all tools, testing-machines, materials, and men necessary for the required testing, inspection, and weighing at the foundry of the pipes and special castings; and, should the purchaser have no inspector at the works, the contractor shall, if required by the engineer, furnish a sworn statement that all of the tests have been made as specified, this statement to contain the results of the tests upon the test-bars.

POWER OF ENGINEER TO INSPECT.

SECTION 17. The engineer shall be at liberty at all times to inspect the material at the foundry, and the molding, casting,

and coating of the pipes and special castings. The forms, sizes, uniformity, and conditions of all pipes and other castings herein referred to shall be subject to his inspection and approval, and he may reject, without proving, any pipe or other casting which is not in conformity with the specifications or drawings.

INSPECTOR TO REPORT.

SECTION 18. The inspector at the foundry shall report daily to the foundry office all pipes and special castings rejected, with the causes for rejection.

CASTINGS TO BE DELIVERED SOUND AND PERFECT.

SECTION 19. All the pipes and other castings must be delivered in all respects sound and conformable to these specifications. The inspection shall not relieve the contractor of any of his obligations in this respect, and any defective pipe or other castings which may have passed the engineer at the works or elsewhere shall be at all times liable to rejection when discovered, until the final completion and adjustment of the contract; provided, however, that the contractor shall not be held liable for pipes or special castings found to be cracked after they have been accepted at the agreed point of delivery. Care shall be taken in handling the pipes not to injure the coating, and no pipes or other material of any kind shall be placed in the pipes during transportation or at any time after they receive the coating.

DEFINITION OF THE WORD "ENGINEER."

SECTION 20. Wherever the word "engineer" is used herein it shall be understood to refer to the engineer or inspector acting for the purchaser and to his properly authorized agents, limited by the particular duties intrusted to them.

STANDARD PIPE SPECIALS.

The following sections, dimensions, and weights of cast-iron pipe specials were adopted by the American Gaslight Association before it was merged into the American Gas Institute. They are the result of years of consideration and pretty well represent the average gas company requirements.

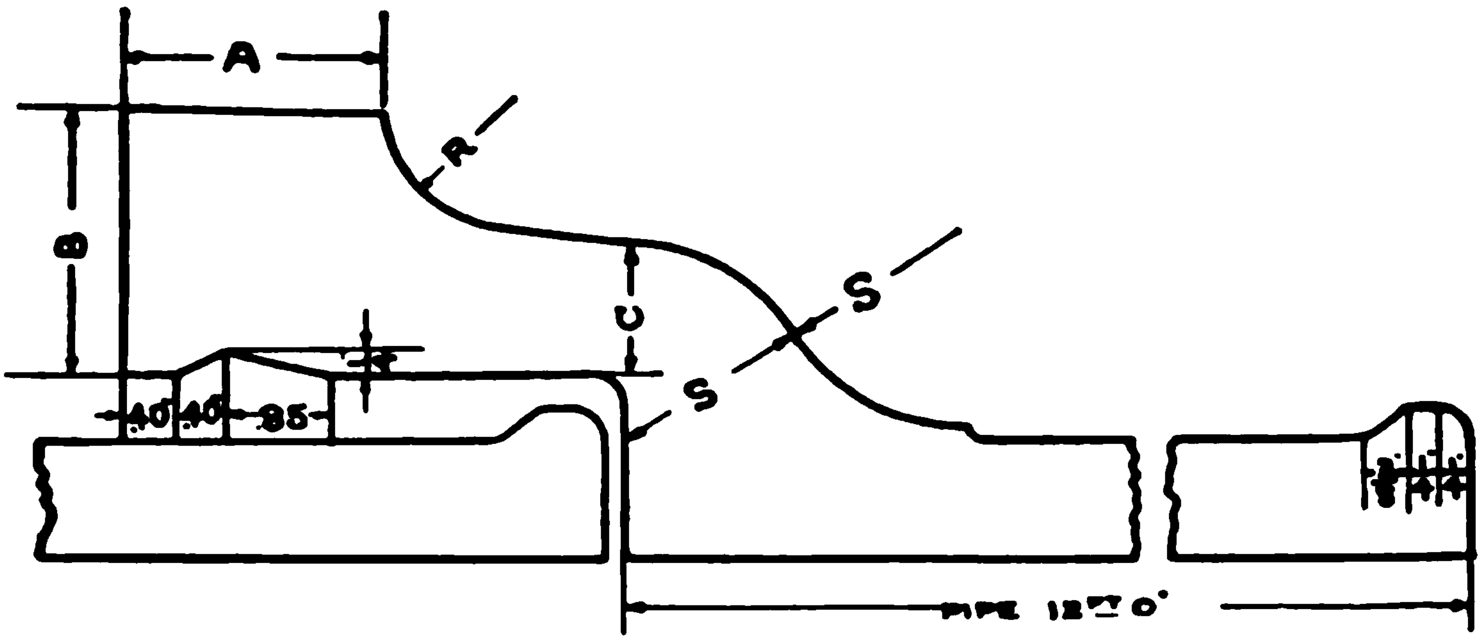


TABLE NO. 1.—GENERAL DIMENSIONS OF PIPES.

Nominal Diameter, Inches.	Classes.	Actual Outside Diameter, Inches.	Diameter of Sockets.		Depth of Sockets.		A	B	C
			Pipe, Inches.	Special Castings, Inches.	Pipe, Inches.	Special Castings, Inches.			
4	A–B	4.80	5.60	5.70	3.50	4.00	1.5	1.30	0.65
4	C–D	5.00	5.80	5.70	3.50	4.00	1.5	1.30	0.65
6	A–B	6.90	7.70	7.80	3.50	4.00	1.5	1.40	0.70
6	C–D	7.10	7.90	7.80	3.50	4.00	1.5	1.40	0.70
8	......	9.05	9.85	10.00	4.00	4.00	1.5	1.50	0.75
8	C–D	9.30	10.10	10.00	4.00	4.00	1.5	1.50	0.75
10	A–B	11.10	11.90	12.10	4.00	4.00	1.5	1.50	0.75
10	C–D	11.40	12.20	12.10	4.00	4.00	1.5	1.60	0.80
12	A–B	13.20	14.00	14.20	4.00	4.00	1.5	1.60	0.80
12	C–D	13.50	14.30	14.20	4.00	4.00	1.5	1.70	0.85
14	A–B	15.30	16.10	16.10	4.00	4.00	1.5	1.70	0.85
14	C–D	15.65	16.45	16.45	4.00	4.00	1.5	1.80	0.90
16	A–B	17.40	18.40	18.40	4.00	4.00	1.75	1.80	0.90
16	C–	17.80	18.80	18.80	4.00	4.00	1.75	1.90	1.00
18	A–B	19.50	20.50	20.50	4.00	4.00	1.75	1.90	0.95
18	C–D	19.92	20.92	20.92	4.00	4.00	1.75	2.10	1.05
20	A–B	21.60	22.60	22.60	4.00	4.00	1.75	2.00	1.00
20	C–D	22.06	23.06	23.06	4.00	4.00	1.75	2.30	1.15
24	A–B	25.80	26.80	26.80	4.00	4.00	2.00	2.10	1.05
24	C–D	26.32	27.32	27.32	4.00	4.00	2.00	2.50	1.25
30	A	31.74	32.74	32.74	4.50	4.50	2.00	2.30	1.15
30	B	32.00	33.00	33.00	4.50	4.50	2.00	2.30	1.15
30	C	32.40	33.40	33.40	4.50	4.50	2.00	2.60	1.32
30	D	32.74	33.74	33.74	4.50	4.50	2.00	3.00	1.50

TABLE NO. 1—*Continued.*

Nominal Diameter, Inches.	Classes.	Actual Outside Diameter, Inches.	Diameter of Sockets.		Depth of Sockets.		*A*	*B*	*C*
			Pipe, Inches.	Special Castings, Inches.	Pipe, Inches.	Special Castings, Inches.			
36	A	37.96	38.96	38.96	4.50	4.50	2.00	2.50	1.25
36	B	38.30	39.30	39.30	4.50	4.50	2.00	2.80	1.40
36	C	38.70	39.70	39.70	4.50	4.50	2.00	3.10	1.60
36	D	39.16	40.16	40.16	4.50	4.50	2.00	3.40	1.80
42	A	44.20	45.20	45.20	5.00	5.00	2.00	2.80	1.40
42	B	44.50	45.50	45.50	5.00	5.00	2.00	3.00	1.50
42	C	45.10	46.10	46.10	5.00	5.00	2.00	3.40	1.75
42	D	45.58	46.58	46.58	5.00	5.00	2.00	3.80	1.95
48	A	50.50	51.50	51.50	5.00	5.00	2.00	3.00	1.50
48	B	50.80	51.80	51.80	5.00	5.00	2.00	3.30	1.65
48	C	51.40	52.40	52.40	5.00	5.00	2.00	3.80	1.95
48	D	51.98	52.98	52.98	5.00	5.00	2.00	4.20	2.20
54	A	56.66	57.66	57.66	5.50	5.50	2.25	3.20	1.60
54	B	57.10	58.10	58.10	5.50	5.50	2.25	3.60	1.80
54	C	57.80	58.80	58.80	5.50	5.50	2.25	4.00	2.15
54	D	58.40	59.40	59.40	5.50	5.50	2.25	4.40	2.45
60	A	62.80	63.80	63.80	5.50	5.50	2.25	3.40	1.70
60	B	63.40	64.40	64.40	5.50	5.50	2.25	3.70	1.90
60	C	64.20	65.20	65.20	5.50	5.50	2.25	4.20	2.25
60	D	64.82	65.82	85.62	5.50	5.50	2.25	4.70	2.60

TABLE NO. 2.—STANDARD THICKNESSES AND WEIGHTS OF CAST-IRON PIPE.

Inside Diameter, Inches.	Class A, 100 Ft. Head, 43 Lbs. Pressure.			Class B, 200 Ft. Head, 86 Lbs. Pressure.		
	Thickness, Inches.	Weight per Foot.	Weight per Length.	Thickness, Inches.	Weight per Foot.	Weight per Length.
4	0.40	20.0	240	0.45	21.7	260
6	0.44	30.8	370	0.48	33.3	400
8	0.46	42.9	515	0.51	47.5	570
10	0.50	57.1	685	0.57	63.8	765
12	0.54	72.5	870	0.62	82.1	985
14	0.57	89.6	1075	0.66	102.5	1230
16	0.60	108.3	1300	0.70	125.0	1500
18	0.64	129.2	1550	0.75	150.0	1800
20	0.67	150.0	1800	0.80	175.0	2100
24	0.76	204.2	2450	0.89	233.3	2800
30	0.88	291.7	3500	1.03	333.3	4000
36	0.99	391.7	4700	1.15	454.2	5450
42	1.10	512.5	6150	1.28	591.7	7100
48	1.26	666.7	8000	1.42	750.0	9000
54	1.35	800.0	9600	1.55	933.3	11200
60	1.39	916.7	11000	1.67	1104.2	13250

Inside Diameter, Inches.	Class C, 300 Ft. Head, 130 Lbs. Pressure.			Class D, 400 Ft. Head, 173 Lbs. Pressure.		
	Thickness, Inches.	Weight per Foot.	Weight per Length.	Thickness, Inches.	Weight per Foot.	Weight per Length.
4	0.48	23.3	280	0.52	25.0	300
6	0.51	35.8	430	0.55	38.3	460
8	0.56	52.1	625	0.60	55.8	670
10	0.62	70.8	850	0.68	76.7	920
12	0.68	91.7	1100	0.75	100.0	1200
14	0.74	116.7	1400	0.82	129.2	1550
16	0.80	143.8	1725	0.89	158.3	1900
18	0.87	175.0	2100	0.96	191.7	2300
20	0.92	208.3	2500	1.03	229.2	2750
24	1.04	279.2	3350	1.16	306.7	3680
30	1.20	400.0	4800	1.37	450.0	5400
36	1.36	545.8	6550	1.58	625.0	7500
42	1.54	716.7	8600	1.78	825.0	9900
48	1.71	908.3	10900	1.96	1050.0	12600
54	1.90	1141.7	13700	2.23	1341.7	16100
60	2.00	1341.7	16100	2.38	1583.3	19000

The above weights are for 12-feet laying lengths and standard sockets; proportionate allowance to be made for any variation therefrom.

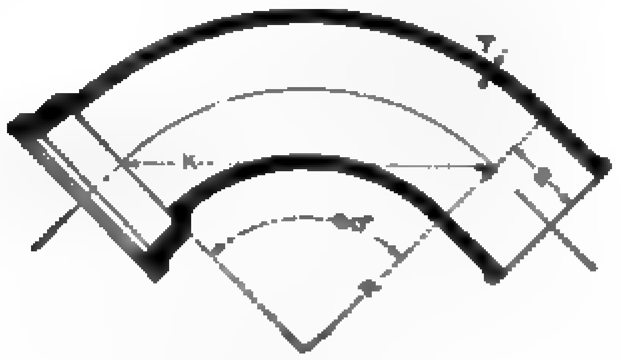


TABLE NO. 3.—ONE-QUARTER CURVES.
(Dimensions in Inches.)

Nominal Diameter.	Class.	T	R	K	S
4	D	0 52	16	22.6	8
6	D	0.55	16	22.6	8
8	D	0 60	16	22.6	10
10	D	0 68	16	22.6	12
12	D	0.75	16	22.6	12
14	A–B	0 66	18	25.5	12
14	C–D	0.82	18	25.5	12
16	A–B	0 70	24	34.	12
16	C–D	0 89	24	34.	12
18	A–B	0 75	24	34.	12
18	C–D	0 96	24	34.	12
20	A–B	0.80	24	34	12
20	C–D	1 03	24	34.	12
24	A–B	0 89	30	42 4	12
24	C–D	1.16	30	42.4	12
30	A	0 88	36	50 9	12
30	B	1 03	36	50.9	12
30	C	1 20	36	50.9	12
30	D	1 37	36	50 9	12
36	A	0·99	48	67 9	12
36	B	1 15	48	67 9	12
36	C	1 36	48	67.9	12
36	D	1 58	48	67.9	12
42	A	1 10	48	67 9	12
42	B	1.28	48	67.9	12
42	C	1.54	48	67 9	12
42	D	1 78	48	67.9	12
48	A	1.26	48	67.9	12
48	B	1 42	48	67 9	12
48	C	1 71	48	67.9	12
48	D	1.96	48	67.9	12
54	A	1.35	54	76.36	12
54	B	1.55	54	76.36	12
54	C	1 90	54	76.36	12
54	D	2.23	54	76.36	12
60	A	1.39	60	84.85	12
60	B	1.67	60	84.85	12
60	C	2.00	60	84.85	12
60	D	2.38	60	84.85	12

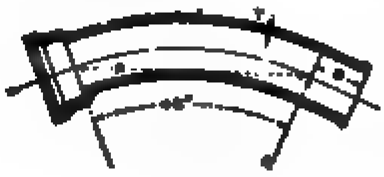


TABLE NO. 4.—ONE-EIGHTH AND ONE-SIXTEENTH CURVES.

(Dimensions in Inches.)

Nominal Diameter.	Class.	T	One-eighth Curves.			One-sixteenth Curves.	
			R	K	S	R	K
4	D	0.52	24	18.4	4	48	18.7
6	D	0.55	24	18.4	4	48	18.7
8	D	0.60	24	18.4	4	48	18.7
10	D	0.68	24	18.4	4	48	18.7
12	D	0.75	24	18.4	4	48	18.7
14	A–B	0.66	36	27.6	..	72	28.1
14	C–D	0.82	36	27.6	..	72	28.1
16	A–B	0.70	36	27.6	..	72	28.1
16	C–D	0.89	36	27.6	..	72	28.1
18	A–B	0.75	36	27.6	..	72	28.1
18	C–D	0.96	36	27.6	..	72	28.1
20	A–B	0.80	48	36.7	..	96	37.5
20	C–D	1.03	48	36.7	..	96	37.5
24	A–B	0.89	60	45.9	..	120	46.8
24	C–D	1.16	60	45.9	..	120	46.8
30	A	0.88	60	45.9	..	120	46.8
30	B	1.03	60	45.9	..	120	46.8
30	C	1.20	60	45.9	..	120	46.8
[illegible]	D	1.37	60	45.9	..	120	46.8
36	A	0.99	90	68.9	..	180	70.2
36	B	1.15	90	68.9	..	180	70.2
36	C	1.36	90	68.9	..	180	70.2
36	D	1.58	90	68.9	..	180	70.2
42	A	1.10	90	68.9	..	180	70.2
42	B	1.28	90	68.9	..	180	70.2
42	C	1.54	90	68.9	..	180	70.2
42	D	1.78	90	68.9	..	180	70.2
48	A	1.26	90	68.9	..	180	70.2
48	B	1.42	90	68.9	..	180	70.2
48	C	1.71	90	68.9	..	180	70.2
48	D	1.96	90	68.9	..	180	70.2
54	A	1.35	90	68.9	..	180	70.2
54	B	1.55	90	68.9	..	180	70.2
54	C	1.90	90	68.9	..	180	70.2
54	D	2.23	90	68.9	..	180	70.2
60	A	1.39	90	68.9	..	180	70.2
60	B	1.67	90	68.9	..	180	70.2
60	C	2.00	90	68.9	..	180	70.2
60	D	2.38	90	68.9	..	180	70.2

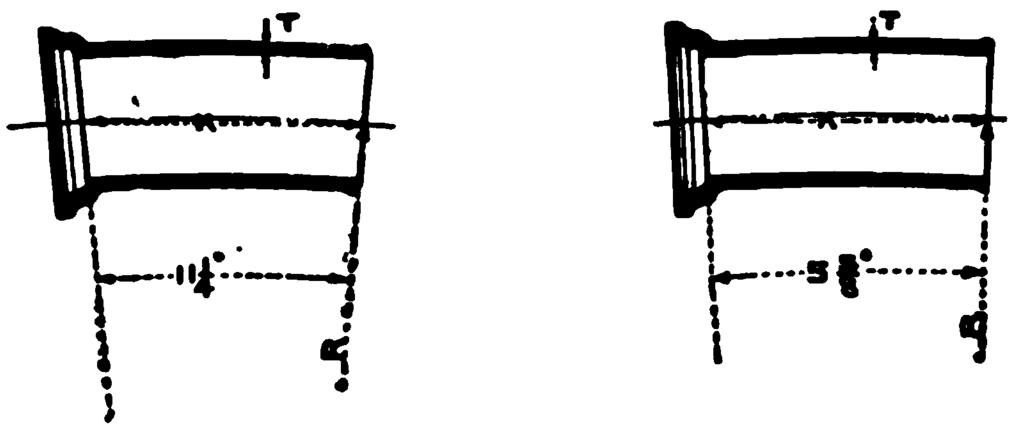


TABLE NO. 5.—ONE-THIRTY-SECOND AND ONE-SIXTY-FOURTH CURVES.

(Dimensions in Inches.)

Nominal Diameter.	Class.	T	One-thirty-second Curves.		One-sixty-fourth Curves.	
			R	K	R	K
20	A–B	0.80	240	47.05	480	47.10
20	C–D	1.03	240	47.05	480	47.10
24	A–B	0.89	240	47.05	480	47.10
24	C–D	1.16	240	47.05	480	47.10
30	A	0.88	240	47.05	480	47.10
30	B	1.03	240	47.05	480	47.10
30	C	1.20	240	47.05	480	47.10
30	D	1.37	240	47.05	480	47.10
36	A	0.99	240	47.05	480	47.10
36	B	1.15	240	47.05	480	47.10
36	C	1.36	240	47.05	480	47.10
36	D	1.58	240	47.05	480	47.10
42	A	1.10	240	47.05	480	47.10
42	B	1.28	240	47.05	480	47.10
42	C	1.54	240	47.05	480	47.10
42	D	1.78	240	47.05	480	47.10
48	A	1.26	240	47.05	480	47.10
48	B	1.42	240	47.05	480	47.10
48	C	1.71	240	47.05	480	47.10
48	D	1.96	240	47.05	480	47.10
54	A	1.35	240	47.05	480	47.10
54	B	1.55	240	47.05	480	47.10
54	C	1.90	240	47.05	480	47.10
54	D	2.23	240	47.05	480	47.10
60	A	1.39	240	47.05	480	47.10
60	B	1.67	240	47.05	480	47.10
60	C	2.00	240	47.05	480	47.10
60	D	2.38	240	47.05	480	47.10

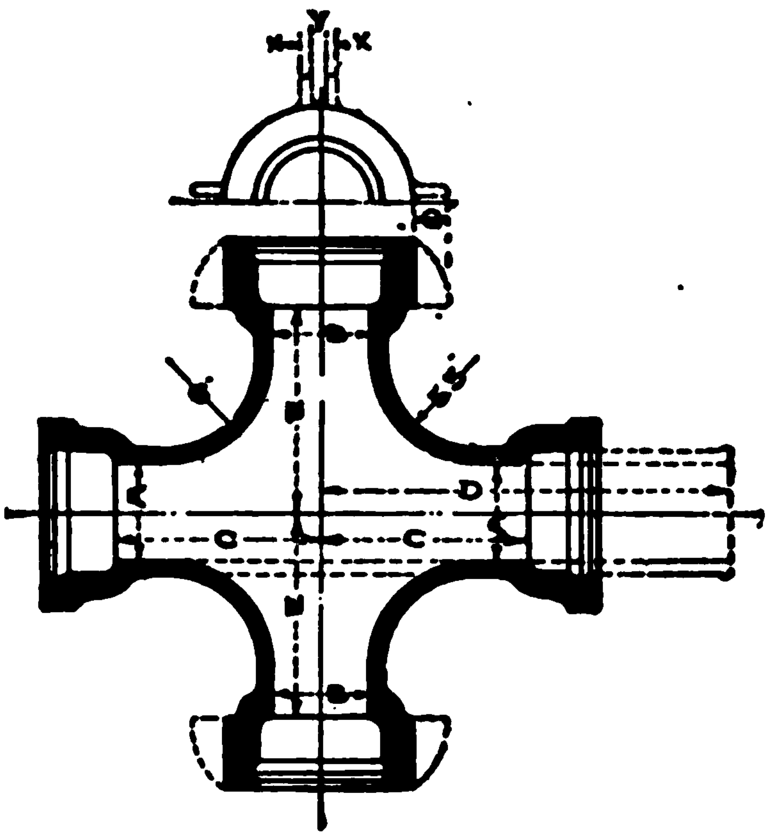


TABLE NO. 6.—BRANCHES.

(Dimensions in Inches.)

Nominal Diam. *A*	*B*	*C*	*D*	*E*	*X*	*Y*	*G*	Class.
4	4	11	23	11	....	....	....	D
6	4	12	24	12	....	....	....	D
6	6	12	24	12	....	....	....	D
8	4	13	25	13	....	....	....	D
8	6	13	25	13	....	....	....	D
8	8	13	25	13	....	....	....	D
10	4	14	26	14	....	....	....	D
10	6	14	26	14	....	....	....	D
10	8	14	26	14	....	....	....	D
10	10	14	26	14	....	....	....	D
12	4	15	27	15	....	....	....	D
12	6	15	27	15	....	....	....	D
12	8	15	27	15	....	....	....	D
12	10	15	27	15	....	....	....	D
12	12	15	27	15	1.25	1.62	2.50	D
14	4	16	28	16	....	....	....	A–B
14	4	16	28	16	....	....	....	C–D
14	6	16	28	16	....	....	....	A–B
14	6	16	28	16	....	....	....	C–D
14	8	16	28	16	....	....	....	A–B
14	8	16	28	16	....	....	....	C–D
14	10	16	28	16	....	....	....	A–B
14	10	16	28	16	....	....	....	C–D
14	12	16	28	16	1.25	1.62	2.50	A–B
14	12	16	28	16	1.25	1.62	2.50	C–D

TABLE NO. 6.—BRANCHES (*Continued*).

(Dimensions in Inches.)

Nominal Diam. *A*	*B*	*C*	*D*	*E*	*X*	*Y*	*G*	Class.
14	14	16	28	16	1.25	1.62	2.50	A–B
14	14	16	28	16	1.25	1.62	2.50	C–D
16	4	17	29	17	....	....	....	A–B
16	4	17	29	17	....	....	....	C–D
16	6	17	29	17	....	....	....	A–B
16	6	17	29	17	....	....	....	C–D
16	6	17	29	17	....	....	....	A–B
16	6	17	29	17	....	....	....	C–D
16	8	17	29	17	....	....	....	A–B
16	8	17	29	17	....	....	....	C–D
16	10	17	29	17	....	....	....	A–B
16	10	17	29	17	....	....	....	C–D
16	12	17	29	17	1.25	1.62	2.50	A–B
16	12	17	29	17	1.25	1.62	2.50	C–D
16	14	17	29	17	1.25	1.62	2.50	A–B
16	14	17	29	17	1.25	1.62	2.50	C–D
16	16	17	29	17	1.25	1.62	2.50	A–B
16	16	17	29	17	1.25	1.62	2.50	C–D
18	4	18	30	18	....	....	....	A–B
18	4	18	30	18	....	....	....	C–D
18	6	18	30	18	....	....	....	A–B
18	6	18	30	18	....	....	....	C–D
18	8	18	30	18	....	....	....	A–B
18	8	18	30	18	....	....	....	C–D
18	10	18	30	18	....	....	....	A–B
18	10	18	30	18	....	....	....	C–D
18	12	18	30	18	1.25	1.62	2.50	A–B
18	12	18	30	18	1.25	1.62	2.50	C–D
18	14	18	30	18	1.25	1.62	2.50	A–B
18	14	18	30	18	1.25	1.62	2.50	C–D
18	16	18	30	18	1.25	1.62	2.50	A–B
18	16	18	30	18	1.25	1.62	2.50	C–D
18	18	18	30	18	1.25	1.62	2.50	A–B
18	18	18	30	18	1.25	1.62	2.50	C–D
20	6	19	31	19	1.25	1.62	2.50	A–B
20	6	19	31	19	....	....	....	C–D
20	8	19	31	19	....	....	....	A–B
20	8	19	31	19	....	....	....	C–D
20	10	19	31	19	....	....	....	A–B
20	10	19	31	19	....	....	....	C–D
20	12	19	31	19	1.25	1.62	2.50	A–B
20	12	19	31	19	1.25	1.62	2.50	C–D
20	14	19	31	19	1.25	1.62	2.50	A–B
20	14	19	31	19	1.25	1.62	2.50	C–D
20	16	19	31	19	1.25	1.62	2.50	A–B
20	16	19	31	19	1.25	1.62	2.50	C–D
20	18	19	31	19	1.25	1.62	2.50	A–B
20	18	19	31	19	1.25	1.62	2.50	C–D

TABLE NO. 6.—BRANCHES (*Continued*).

(Dimensions in Inches.)

Nominal Diam. *A*	*B*	*C*	*D*	*E*	*X*	*Y*	*G*	Class.
20	20	19	31	19	1.25	1.62	2.50	A–B
20	20	19	31	19	1.25	1.62	2.50	C–D
24	6	21	33	21	.....	.....	.....	A–B
24	6	21	33	21	.....	.....	.....	C–D
24	8	21	33	21	.....	.....	.....	A–B
24	8	21	33	21	.....	.....	.....	C–D
24	10	21	33	21	.....	.....	.....	A–B
24	10	21	33	21	.....	.....	.....	C–D
24	12	21	33	21	1.25	1.62	2.50	A–B
24	12	21	33	21	1.25	1.62	2.50	C–D
24	14	21	33	21	1.25	1.62	2.50	A–B
24	14	21	33	21	1.25	1.62	2.50	C–D
24	16	21	33	21	1.25	1.62	2.50	A–B
24	16	21	33	21	1.25	1.62	2.50	C–D
24	18	21	33	21	1.25	1.62	2.50	A–B
24	18	21	33	21	1.25	1.62	2.50	C–D
24	20	21	33	21	1.25	1.62	2.50	A–B
24	20	21	33	21	1.25	1.62	2.50	C–D
24	24	21	33	21	1.25	1.62	2.50	A–B
24	24	21	33	21	1.25	1.62	2.50	C–D
30	12	15	27	24	1.25	1.62	2.50	A
30	12	15	27	24	1.25	1.62	2.50	B
30	12	15	27	24	1.25	1.62	2.50	C
30	12	15	27	24	1.25	1.62	2.50	D
30	14	16	28	24	1.25	1.62	2.50	A
30	14	16	28	24	1.25	1.62	2.50	B
30	14	16	28	24	1.25	1.62	2.50	C
30	14	16	28	24	1.25	1.62	2.50	D
30	16	17	29	24	1.25	1.62	2.50	A
30	16	17	29	24	1.25	1.62	2.50	B
30	16	17	29	24	1.25	1.62	2.50	C
30	16	17	29	24	1.25	1.62	2.50	D
30	18	18	32	24	1.25	1.62	2.50	A
30	18	18	32	24	1.25	1.62	2.50	B
30	18	18	32	24	1.25	1.62	2.50	C
30	18	18	32	24	1.25	1.62	2.50	D
30	20	19	34	24	1.25	1.62	2.50	A
30	20	19	34	24	1.25	1.62	2.50	B
30	20	19	34	24	1.25	1.62	2.50	C
30	20	19	34	24	1.25	1.62	2.50	D
30	24	21	36	24	1.25	1.62	2.50	A
30	24	21	36	24	1.25	1.62	2.50	B
30	24	21	36	24	1.25	1.62	2.50	C
30	24	21	36	24	1.25	1.62	2.50	D
30	30	24	41	24	1.50	2.00	3.00	A
30	30	24	41	24	1.50	2.00	3.00	B
30	30	24	41	24	1.50	2.00	3.00	C
30	30	24	41	24	1.50	2.00	3.00	D

TABLE NO. 6.—BRANCHES (*Continued*).

(Dimensions in Inches.)

Nominal Diam. *A*	*B*	*C*	*D*	*E*	*X*	*Y*	*G*	Class.
36	12	15	27	27	1.25	1.62	2.50	A
36	12	15	27	27	1.25	1.62	2.50	B
36	12	15	27	27	1.25	1.62	2.50	C
36	12	15	27	27	1.25	1.62	2.50	D
36	14	16	28	27	1.25	1.62	2.50	A
36	14	16	28	27	1.25	1.62	2.50	B
36	14	16	28	27	1.25	1.62	2.50	C
36	14	16	28	27	1.25	1.62	2.50	D
36	16	17	29	27	1.25	1.62	2.50	A
36	16	17	29	27	1.25	1.62	2.50	B
36	16	17	29	27	1.25	1.62	2.50	C
36	16	17	29	27	1.25	1.62	2.50	D
36	18	18	32	27	1.25	1.62	2.50	A
36	18	18	32	27	1.25	1.62	2.50	B
36	18	18	32	27	1.25	1.62	2.50	C
36	18	18	32	27	1.25	1.62	2.50	D
36	20	19	34	27	1.25	1.62	2.50	A
36	20	19	34	27	1.25	1.62	2.50	B
36	20	19	34	27	1.25	1.62	2.50	C
36	20	19	34	27	1.25	1.62	2.50	D
36	24	21	36	27	1.25	1.62	2.50	A
36	24	21	36	27	1.25	1.62	2.50	B
36	24	21	36	27	1.25	1.62	2.50	C
36	24	21	36	27	1.25	1.62	2.50	D
36	30	24	41	27	1.50	2.00	3.00	A
36	30	24	41	27	1.50	2.00	3.00	B
36	30	24	41	27	1.50	2.00	3.00	C
36	30	24	41	27	1.50	2.00	3.00	D
36	36	27	44	27	1.50	2.00	3.00	A
36	36	27	44	27	1.50	2.00	3.00	B
36	36	27	44	27	1.50	2.00	3.00	C
36	36	27	44	27	1.50	2.00	3.00	D
42	12	15	27	30	1.25	1.62	2.50	A
42	12	15	27	30	1.25	1.62	2.50	B
42	12	15	27	30	1.25	1.62	2.50	C
42	12	15	27	30	1.25	1.62	2.50	D
42	14	16	28	30	1.25	1.62	2.50	A
42	14	16	28	30	1.25	1.62	2.50	B
42	14	16	28	30	1.25	1.62	2.50	C
42	14	16	28	30	1.25	1.62	2.50	D
42	16	17	29	30	1.25	1.62	2.50	A
42	16	17	29	30	1.25	1.62	2.50	B
42	16	17	29	30	1.25	1.62	2.50	C
42	16	17	29	30	1.25	1.62	2.50	D
42	18	18	32	30	1.25	1.62	2.50	A
42	18	18	32	30	1.25	1.62	2.50	B
42	18	18	32	30	1.25	1.62	2.50	C
42	18	18	32	30	1.25	1.62	2.50	D

TABLE NO. 6.—BRANCHES (*Continued*).
(Dimensions in Inches.)

Nominal Diam. *A*	[illegible]	*C*	*D*	[illegible]	*X*	*Y*	*G*	Class.
42	20	19	34	30	1.25	1.62	2.50	A
42	20	19	34	30	1.25	1.62	2.50	B
42	20	19	34	30	1.25	1.62	2.50	C
42	20	19	34	30	1.25	1 62	2.50	D
42	24	21	36	30	1.25	1 62	2.50	A
42	24	21	36	30	1.25	1.62	2.50	B
42	24	21	36	30	1.25	1 62	2.50	C
42	24	21	36	30	1.25	1.62	2.50	D
42	30	24	41	30	1.50	2.00	3 00	A
42	30	24	41	30	1.50	2.00	3 00	B
42	30	24	41	30	1.50	2.00	3.00	C
42	30	24	41	30	1.50	2.00	3.00	D
42	36	27	44	30	1 50	2.00	3.00	A
42	36	27	44	30	1.50	2.00	3.00	B
42	36	27	44	30	1.50	2.00	3.00	C
42	36	27	44	30	1 50	2.00	3.00	D
42	42	30	47	30	1.50	2.00	3.00	A
42	42	30	47	30	1.50	2.00	3.00	B
42	42	30	47	30	1.50	2.00	3.00	C
42	42	30	47	30	1.50	2 00	3.00	D
48	16	17	29	33	1.25	1.62	2.50	A
48	16	17	29	33	1.25	1 62	2.50	B
48	16	17	29	33	1.25	1.62	2.50	C
48	16	17	29	33	1.25	1 62	2.50	D
48	18	18	32	33	1.25	1.62	2.50	A
48	18	18	32	33	1.25	1 62	2 50	B
48	18	18	32	33	1.25	1.62	2.50	C
48	18	18	32	33	1.25	1.62	2.50	D
48	20	19	34	33	1.25	1.62	2.50	A
48	20	19	34	33	1.25	1.62	2.50	B
48	20	19	34	33	1.25	1.62	2.50	C
48	20	19	34	33	1.25	1.62	2.50	D
48	24	21	36	33	1.25	1.62	2,50	A
48	24	21	36	33	1 25	1.62	2.50	B
48	24	21	36	33	1.25	1.62	2 50	C
48	24	21	36	33	1 25	1.62	2.50	D
48	30	24	41	33	1.50	2.00	3.00	A
48	30	24	41	33	1.50	2.00	3.00	B
48	30	24	41	33	1.50	2.00	3.00	C
48	30	24	41	33	1.50	2.00	3.00	D
48	36	27	44	33	1.50	2.00	3.00	A
48	36	27	44	33	1.50	2.00	3.00	B
48	36	27	44	33	1.50	2.00	3.00	C
48	36	27	44	33	1.50	2.00	3.00	D
48	42	30	47	33	1.50	2.00	3.00	A
48	42	30	47	33	1.50	2.00	3.00	B
48	42	30	47	33	1.50	2.00	3.00	C
48	42	30	47	33	1.50	2.00	3.00	D

TABLE NO. 6.—BRANCHES (*Continued*).

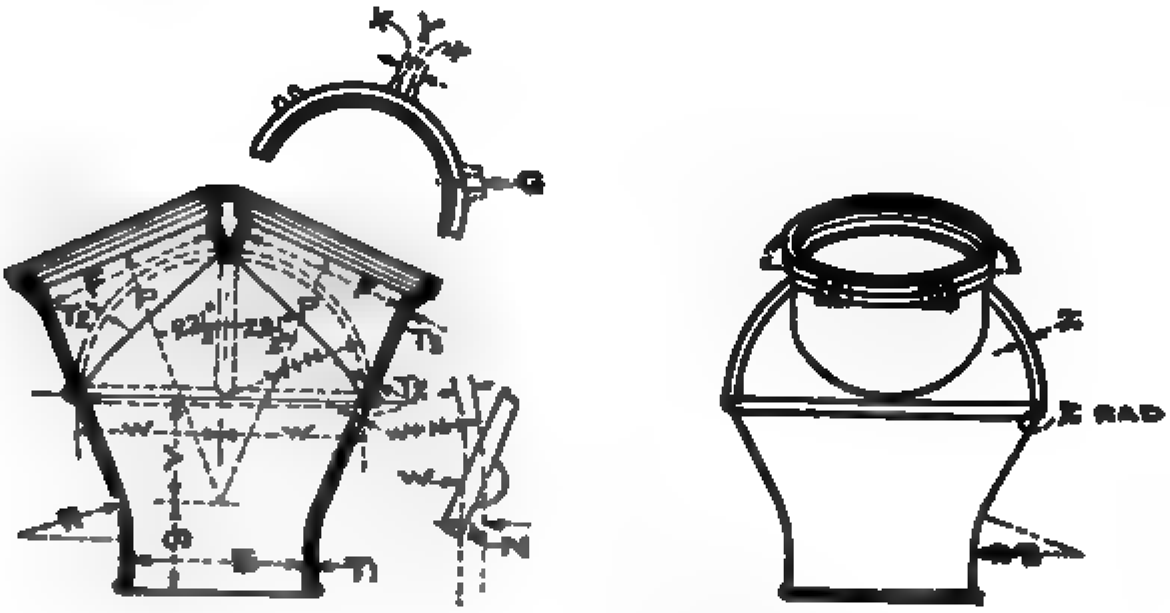
(Dimensions in Inches.)

Nominal Diam. *A*	*B*	*C*	*D*	*E*	*X*	*Y*	*G*	Class.
48	48	33	50	33	1.50	2.00	3.00	A
48	48	33	50	33	1.50	2.00	3.00	B
48	48	33	50	33	1.50	2.00	3.00	C
48	48	33	50	33	1.50	2.00	3.00	D
54	16	17	29	36	1.25	1.62	2.50	A
54	16	17	29	36	1.25	1.62	2.50	B
54	16	17	29	36	1.25	1.62	2.50	C
54	16	17	29	36	1.25	1.62	2.50	D
54	18	18	32	36	1.25	1.62	2.50	A
54	18	18	32	36	1.25	1.62	2.50	B
54	18	18	32	36	1.25	1.62	2.50	C
54	18	18	32	36	1.25	1.62	2.50	D
54	20	19	34	36	1.25	1.62	2.50	A
54	20	19	34	36	1.25	1.62	2.50	B
54	20	19	34	36	1.25	1.62	2.50	C
54	20	19	34	36	1.25	1.62	2.50	D
54	24	21	36	36	1.25	1.62	2.50	A
54	24	21	36	36	1.25	1.62	2.50	B
54	24	21	36	36	1.25	1.62	2.50	C
54	24	21	36	36	1.25	1.62	2.50	D
54	30	24	41	36	1.50	2.00	3.00	A
54	30	24	41	36	1.50	2.00	3.00	B
54	30	24	41	36	1.50	2.00	3.00	C
54	30	24	41	36	1.50	2.00	3.00	D
54	36	27	44	36	1.50	2.00	3.00	A
54	36	27	44	36	1.50	2.00	3.00	B
54	36	27	44	36	1.50	2.00	3.00	C
54	36	27	44	36	1.50	2.00	3.00	D
54	42	30	47	36	1.50	2.00	3.00	A
54	42	30	47	36	1.50	2.00	3.00	B
54	42	30	47	36	1.50	2.00	3.00	C
54	42	30	47	36	1.50	2.00	3.00	D
54	48	33	50	36	1.50	2.00	3.00	A
54	48	33	50	36	1.50	2.00	3.00	B
54	48	33	50	36	1.50	2.00	3.00	C
54	48	33	50	36	1.50	2.00	3.00	D
54	54	36	53	36	1.50	2.00	3.00	A
54	54	36	53	36	1.50	2.00	3.00	B
54	54	36	53	36	1.50	2.00	3.00	C
54	54	36	53	36	1.50	2.00	3.00	D
60	16	17	29	39	1.25	1.62	2.50	A
60	16	17	29	39	1.25	1.62	2.50	B
60	16	17	29	39	1.25	1.62	2.50	C
60	16	17	29	39	1.25	1.62	2.50	D
60	18	18	32	39	1.25	1.62	2.50	A
60	18	18	32	39	1.25	1.62	2.50	B
60	18	18	32	39	1.25	1.62	2.50	C
60	18	18	32	39	1.25	1.62	2.50	D

TABLE NO. 6.—BRANCHES (*Continued*).

(Dimensions in Inches.)

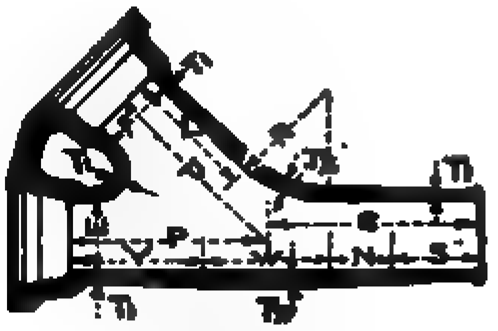
Nominal Diam. *A*	*B*	*C*	*D*	*E*	*X*	*Y*	*G*	Class.
60	20	19	34	39	1.25	1.62	2.50	A
60	20	19	34	39	1.25	1.62	2.50	B
60	20	19	34	39	1.25	1.62	2.50	C
60	20	19	34	39	1.25	1.62	2.50	D
60	24	21	36	39	1.25	1.62	2.50	A
60	24	21	36	39	1.25	1.62	2.50	B
60	24	21	36	39	1.25	1.62	2.50	C
60	24	21	36	39	1.25	1.62	2.50	D
60	30	24	41	39	1.50	2.00	3.00	A
60	30	24	41	39	1.50	2.00	3.00	B
60	30	24	41	39	1.50	2.00	3.00	C
60	30	24	41	39	1.50	2.00	3.00	D
60	36	27	44	39	1.50	2.00	3.00	A
60	36	27	44	39	1.50	2.00	3.00	B
60	36	27	44	39	1.50	2.00	3.00	C
60	36	27	44	39	1.50	2.00	3.00	D
60	42	30	47	39	1.50	2.00	3.00	A
60	42	30	47	39	1.50	2.00	3.00	B
60	42	30	47	39	1.50	2.00	3.00	C
60	42	30	47	39	1.50	2.00	3.00	D
60	48	33	50	39	1.50	2.00	3.00	A
60	48	33	50	39	1.50	2.00	3.00	B
60	48	33	50	39	1.50	2.00	3.00	C
60	48	33	50	39	1.50	2.00	3.00	D
60	54	36	53	39	1.50	2.00	3.00	A
60	54	36	53	39	1.50	2.00	3.00	B
60	54	36	53	39	1.50	2.00	3.00	C
60	54	36	53	39	1.50	2.00	3.00	D
60	60	39	56	39	1.50	2.00	3.00	A
60	60	39	56	39	1.50	2.00	3.00	B
60	60	39	56	39	1.50	2.00	3.00	C
60	60	39	56	39	1.50	2.00	3.00	D



TYPE 1.—12″ to 48″.

G = 2.50″ for 12″ to 24″ bells.
X = 1.25″ for 12″ to 24″ bells.
Y = 1.62″ for 12″ to 24″ bells.
Z = 1.00″ for 12″ to 14″ bells.

G = 3.00″ for 30″ to 60″ bells.
X = 1.50″ for 30″ to 60″ bells.
Y = 2.00″ for 30″ to 60″ bells.
Z = 1.25″ for 16″ to 30″ bells.
Z = 1.50″ for 36″ to 60″ bells.



TYPE 2.—4″ to 16″.

TABLE NO. 7.—Y BRANCHES.
(Dimensions in Inches.)

Nom. Diam.		S	P	V	W	N	R	T_1	T_2	T_3	Type	Class.
E	F											
4	4	11.5	10.5	7.18	6.64	3.18	6	0.52	0.65	.....	2	D
6	6	13.0	13.0	9.27	7.46	4.27	6	0.55	0.68	.....	2	D
8	8	14.0	16.0	11.85	8.30	4.85	6	0.60	0.72	.....	2	D
10	10	15.5	18.5	13.94	9.12	5.94	6	0.68	0.85	.....	2	D
12	12	15.5	21.5	16.54	9.92	5.54	[illegible]	0.75	0.95	.....	2	D
12	12	16.0	21.5	8.00	9.79	1.19	30	0.75	1.10	0.75	1	D
14	14	16.0	24.0	18.62	10.76	5.62	6	0.66	0.80	.....	2	A–B
14	14	16.0	24.0	18.62	10.76	5.62	6	0.82	1.00	.....	2	C–D
14	14	16.0	24.0	9.00	11.30	1.00	30	0.66	0.90	0.66	1	A–B
14	14	16.0	24.0	9.00	11.30	1.29	30	0.82	1.19	0.82	1	C–D

TABLE NO. 7.—Y BRANCHES (*Continued*).
(Dimensions in Inches.)

Nom. Diam. E	Nom. Diam. F	S	P	V	W	N	R	T_1	T_2	T_3	Class.
16	16	17.5	27.5	21.70	11.60	6.70	6	0.70	0.85	....	A-B
16	16	17.5	27.5	21.70	11.60	6.70	6	0.89	1.10	.....	C-D
16	16	17.0	27.5	10.50	13.00	1.10	30	0.70	1.00	0.70	A-B
16	16	17.0	27.5	10.50	13.00	1.50	30	0.89	1.30	0.89	C-D
18	18	18.0	30.0	12.0	14.7	1.17	30	0.75	1.08	0.75	A-B
18	18	18.0	30.0	12.0	14.7	1.36	30	0.96	1.40	0.96	C-D
20	20	18.0	34.0	13.5	16.4	1.25	30	0.80	1.15	0.80	A-B
20	20	18.0	34.0	13.5	16.4	1.62	30	1.03	1.50	1.03	C-D
24	18	9.0	30.0	12.0	14.7	1.17	30	0.89	1.08	0.75	A-B
24	18	9.0	30.0	12.0	14.7	1.36	30	1.16	1.40	0.96	C-D
24	20	12.0	34.0	13.5	16.4	1.25	30	0.89	1.15	0.80	A-B
24	20	12.0	34.0	13.5	16.4	1.62	30	1.16	1.50	1.03	C-D
24	24	18.0	38.0	15.25	19.3	1.41	30	0.89	1.30	0.89	A-B
24	24	18.0	38.0	15.25	19.3	1.84	30	1.16	1.70	1.16	C-D
30	24	12.0	38.0	15.25	19.3	1.35	30	0.88	1.25	0.89	A
30	24	12.0	38.0	15.25	19.3	1.35	30	1.03	1.25	0.89	B
30	24	12.0	38.0	15.25	19.3	1.79	30	1.20	1.65	1.16	C
30	24	12.0	38.0	15.25	19.3	1.79	30	1.37	1.65	1.16	D
30	30	18	48	18	23.7	1.35	30	0.88	1.25	0.88	A
30	30	18	48	18	23.7	1.62	30	1.03	1.50	1.03	B
30	30	18	48	18	23.7	1.89	30	1.20	1.75	1.20	C
30	30	18	48	18	23.7	2.16	30	1.37	2.00	1.37	D
36	30	10	48	18	23.7	1.35	30	0.99	1.25	0.88	A
36	30	10	48	18	23.7	1.62	30	1.15	1.50	1.03	B
36	30	10	48	18	23.7	1.89	30	1.36	1.75	1.20	C
36	30	10	48	18	23.7	2.16	30	1.58	2.00	1.37	D
36	36	18	54	21	28.2	1.62	24	0.99	1.50	0.99	A
36	36	18	54	21	28.2	1.79	24	1.15	1.65	1.15	B
36	36	18	54	21	28.2	2.16	24	1.36	2.00	1.36	C
36	36	18	54	21	28.2	2.54	24	1.58	2.35	1.58	D
42	30	6	48	18	23.7	1.35	30	1.10	1.25	0.88	A
42	30	6	48	18	23.7	1.62	30	1.28	1.50	1.03	B
42	30	6	48	18	23.7	1.89	30	1.54	1.75	1.20	C
42	30	6	48	18	23.7	2.16	30	1.78	2.00	1.37	D
42	36	10	54	21	28.2	1.62	24	1.10	1.50	0.99	A
42	36	10	54	21	28.2	1.79	24	1.28	1.65	1.15	B
42	36	10	54	21	28.2	2.16	24	1.54	2.00	1.36	C
42	36	10	54	21	28.2	2.54	24	1.78	2.35	1.58	D
42	42	18	60	25	33.1	1.79	24	1.10	1.65	1.10	A
42	42	18	60	25	33.1	1.95	24	1.28	1.80	1.28	B
42	42	18	60	25	33.1	2.44	24	1.54	2.25	1.54	C
42	42	18	60	25	33.1	2.87	24	1.78	2.65	1.78	D
48	36	2	54	21	28.2	1.62	24	1.26	1.50	0.99	A
48	36	2	54	21	28.2	1.79	24	1.42	1.65	1.15	B
48	36	2	54	21	28.2	2.16	24	1.71	2.00	1.36	C
48	36	2	54	21	28.2	2.54	24	1.96	2.35	1.58	D

TABLE NO. 7 (*Continued*).

(Dimensions in Inches.)

Nom. Diam. E	Nom. Diam. F	S	P	V	W	N	R	T_1	T_2	T_3	Class.
48	42	10	60	25	33.1	1.79	24	1.26	1.65	1.10	A
48	42	10	60	25	33.1	1.95	24	1.42	1.80	1.28	B
48	42	10	60	25	33.1	2.44	24	1.71	2.25	1.54	C
48	42	10	60	25	33.1	2.87	24	1.96	2.65	1.78	D
48	48	18	68.5	28	37.6	1.95	24	1.26	1.80	1.26	A
48	48	18	68.5	28	37.6	2.27	24	1.42	2.10	1.42	B
48	48	18	68.5	28	37.6	2.76	24	1.71	2.55	1.71	C
48	48	18	68.5	28	37.6	3.13	24	1.96	2.90	1.96	D
54	36	2	54	21	28.2	1.62	24	1.35	1.50	0.99	A
54	36	2	54	21	28.2	1.79	24	1.55	1.65	1.15	B
54	36	2	54	21	28.2	2.16	24	1.90	2.00	1.36	C
54	36	2	54	21	28.2	2.54	24	2.23	2.35	1.58	D
54	42	6	60	25	33.1	1.75	24	1.35	1.65	1.10	A
54	42	6	60	25	33.1	1.95	24	1.55	1.80	1.28	B
54	42	6	60	25	33.1	2.44	24	1.90	2.25	1.54	C
54	42	6	60	25	33.1	2.87	24	2.23	2.65	1.78	D
54	48	10	68.5	28	37.6	1.95	24	1.35	1.80	1.26	A
54	48	10	68.5	28	37.6	2.27	24	1.55	2.10	1.42	B
54	48	10	68.5	28	37.6	2.76	24	1.90	2.55	1.71	C
54	48	10	68.5	28	37.6	3.13	24	2.23	2.90	1.96	D
54	54	18	78	31	42	2.16	24	1.35	2.00	1.35	A
54	54	18	78	31	42	2.44	24	1.55	2.25	1.55	B
54	54	18	78	31	42	3.08	24	1.90	2.85	1.90	C
54	54	18	78	31	42	3.50	24	2.23	3.25	2.23	D
60	36	2	54	21	28.2	1.62	24	1.39	1.50	0.99	A
60	36	2	54	21	28.2	1.79	24	1.67	1.65	1.15	B
60	36	2	54	21	28.2	2.16	24	2.00	2.00	1.36	C
60	36	2	54	21	28.2	2.54	24	2.38	2.35	1.58	D
60	42	6	60	25	33.1	1.75	24	1.39	1.65	1.10	A
60	42	6	60	25	33.1	1.95	24	1.67	1.80	1.28	B
60	42	6	60	25	33.1	2.44	24	2.00	2.25	1.54	C
60	42	6	60	25	33.1	2.87	24	2.38	2.65	1.78	D
60	48	8	68.5	28	37.6	1.95	24	1.39	1.80	1.26	A
60	48	8	68.5	28	37.6	2.27	24	1.67	2.10	1.42	B
60	48	8	68.5	28	37.6	2.76	24	2.00	2.55	1.71	C
60	48	8	68.5	28	37.6	3.13	24	2.38	2.90	1.96	D
60	54	12	78	31	42	2.16	24	1.39	2.00	1.35	A
60	54	12	78	31	42	2.44	24	1.67	2.25	1.55	B
60	54	12	78	31	42	3.08	24	2.00	2.85	1.90	C
60	54	12	78	31	42	3.50	24	2.38	3.25	2.23	D
60	60	18	90	35	46.7	2.22	24	1.39	2.05	1.39	A
60	60	18	90	35	46.7	2.70	24	1.67	2.50	1.67	B
60	60	18	90	35	46.7	3.25	24	2.00	3.00	2.00	C
60	60	18	90	35	46.7	3.78	24	2.38	3.50	2.38	D

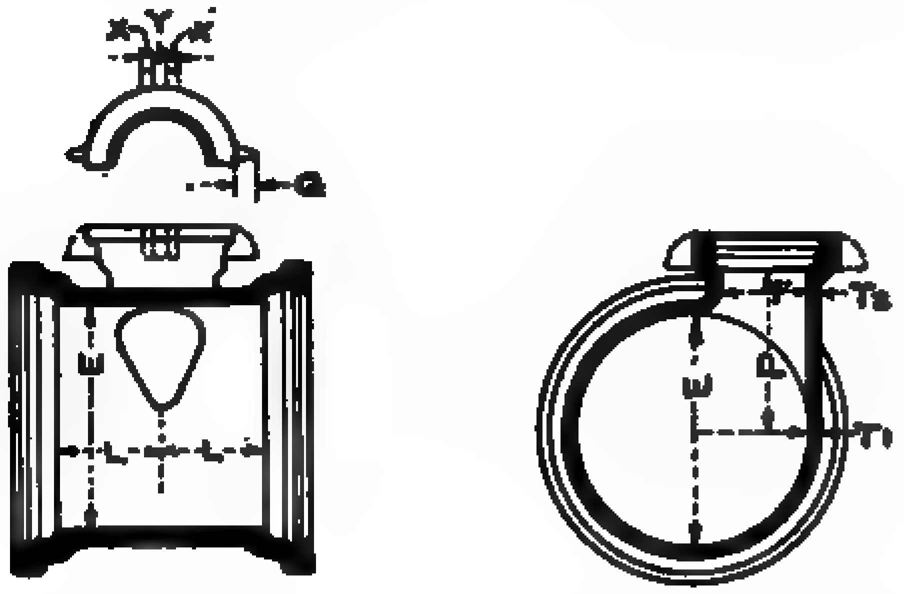


TABLE NO. 8.—BLOW-OFF BRANCHES.

(Dimensions in Inches.)

Nom. Diam. E	Nom. Diam. F	L	P	T_1	T_2	X	Y	G	Class.
8	4	12	7	0.60	0.52	......	......	...	D
10	4	12	8	0.68	0.52	......	......	...	D
10	6	12	8	0.68	0.55	......	......	...	D
12	4	12	10	0.75	0.52	......	......	...	D
12	6	12	10	0.75	0.55	......	......	...	D
14	4	12	11	0.66	0.52	......	......	...	A-B
14	4	12	11	0.82	0.52	......	......	...	C-D
14	6	12	11	0.66	0.55	......	......	...	A-B
14	6	12	11	0.82	0.55	......	......	...	C-D
16	4	12	12	0.70	0.52	......	......	...	A-B
16	4	12	12	0.89	0.52	......	......	...	C-D
16	6	12	12	0.70	0.55	......	......	...	A-B
16	6	12	12	0.89	0.55	......	......	...	C-D
18	4	12	13	0.75	0.52	......	......	...	A-B
18	4	12	13	0.96	0.52	......	......	...	C-D
18	6	12	13	0.75	0.55	......	......	...	A-B
18	6	12	13	0.96	0.55	......	......	...	C-D
20	4	12	14	0.80	0.52	......	......	...	A-B
20	4	12	14	1.03	0.52	......	......	...	C-D
20	6	12	14	0.80	0.55	......	......	...	A-B
20	6	12	14	1.03	0.55	......	......	...	C-D
24	6	12	16	0.89	0.55	......	......	...	A-B
24	6	12	16	1.16	0.55	......	......	...	C-D
24	8	12	16	0.89	0.60	......	......	...	A-B
24	8	12	16	1.16	0.60	......	......	...	C-D
30	8	13	20	0.88	0.60	......	......	...	A
30	8	13	20	1.03	0.60	......	......	...	B
30	8	13	20	1.20	0.60	......	......	...	C
30	[illegible]	13	[illegible]	1.37	0.60	......	......	...	D

TABLE NO. 8 (*Continued*).

(Dimensions in Inches.)

Nom. Diam.		L	P	T_1	T_2	X	Y	G	Class.
E	F								
30	12	13	20	0.88	0.75	1.25	1.62	2.50	A
30	12	13	20	1.03	0.75	1.25	1.62	2.50	B
30	[illegible]	13	20	1.20	0.75	1.25	1.62	2.50	C
[illegible]	12	13	20	1.37	0.75	1.25	1.62	2.50	D
36	8	13	23	0.99	0.60	......	......	......	A
36	8	13	23	1.15	0.60	......	......	......	B
36	8	13	23	1.36	0.60	......	......	......	C
[illegible]	8	13	[illegible]	1.58	0.60	......	......	......	D
36	12	[illegible]	23	0.99	0.75	1.25	1.62	2.50	A
[illegible]	12	13	23	1.15	0.75	1.25	1.62	2.50	B
36	12	13	23	1.36	0.75	1.25	1.62	2.50	C
36	12	13	[illegible]	1.58	0.75	1.25	1.62	2.50	D
42	12	15	26	1.10	0.75	1.25	1.62	2.50	A
42	12	15	26	1.28	0.75	1.25	1.62	2.50	B
42	12	15	26	1.54	0.75	1.25	1.62	2.50	C
42	12	15	26	1.78	0.75	1.25	1.62	2.50	D
42	16	15	26	1.10	0.70	1.25	1.62	2.50	A
42	16	[illegible]	26	1.28	0.70	1.25	1.62	2.50	B
42	16	15	26	1.54	0.89	1.25	1.62	2.50	C
42	16	15	[illegible]	1.78	0.89	1.25	1.62	2.50	D
[illegible]	12	17	[illegible]	1.26	0.75	1.25	1.62	2.50	A
48	12	17	[illegible]	1.42	0.75	1.25	1.62	2.50	B
[illegible]	12	17	30	1.71	0.75	1.25	1.62	2.50	C
48	12	17	30	1.96	0.75	1.25	1.62	2.50	D
48	16	17	30	1.26	0.70	1.25	1.62	2.50	A
48	16	17	30	1.42	0.70	1.25	1.62	2.50	B
48	16	17	30	1.71	0.89	1.25	1.62	2.50	C
[illegible]	16	17	30	1.96	0.89	1.25	1.62	2.50	D
54	12	19	33	1.35	0.75	1.25	1.62	2.50	A
54	12	19	[illegible]	1.55	0.75	1.25	1.62	2.50	B
54	12	19	33	1.90	0.75	1.25	1.62	2.50	C
54	12	19	33	2.23	0.75	1.25	1.62	2.50	D
54	16	19	33	1.35	0.70	1.25	1.62	2.50	A
54	16	19	33	1.55	0.70	1.25	1.62	2.50	B
54	16	19	33	1.90	0.89	1.25	1.62	2.50	C
54	16	19	33	2.23	0.89	1.25	1.62	2.50	D
60	12	21	36	1.39	0.75	1.25	1.62	2.50	A
60	12	21	36	1.67	0.75	1.25	1.62	2.50	B
60	12	21	36	2.00	0.75	1.25	1.62	2.50	C
60	12	21	36	2.38	0.75	1.25	1.62	2.50	D
60	16	21	36	1.39	0.70	1.25	1.62	2.50	A
60	16	21	36	1.67	0.70	1.25	1.62	2.50	B
60	16	21	36	2.00	0.89	1.25	1.62	2.50	C
60	16	21	36	2.38	0.89	1.25	1.62	2.50	D

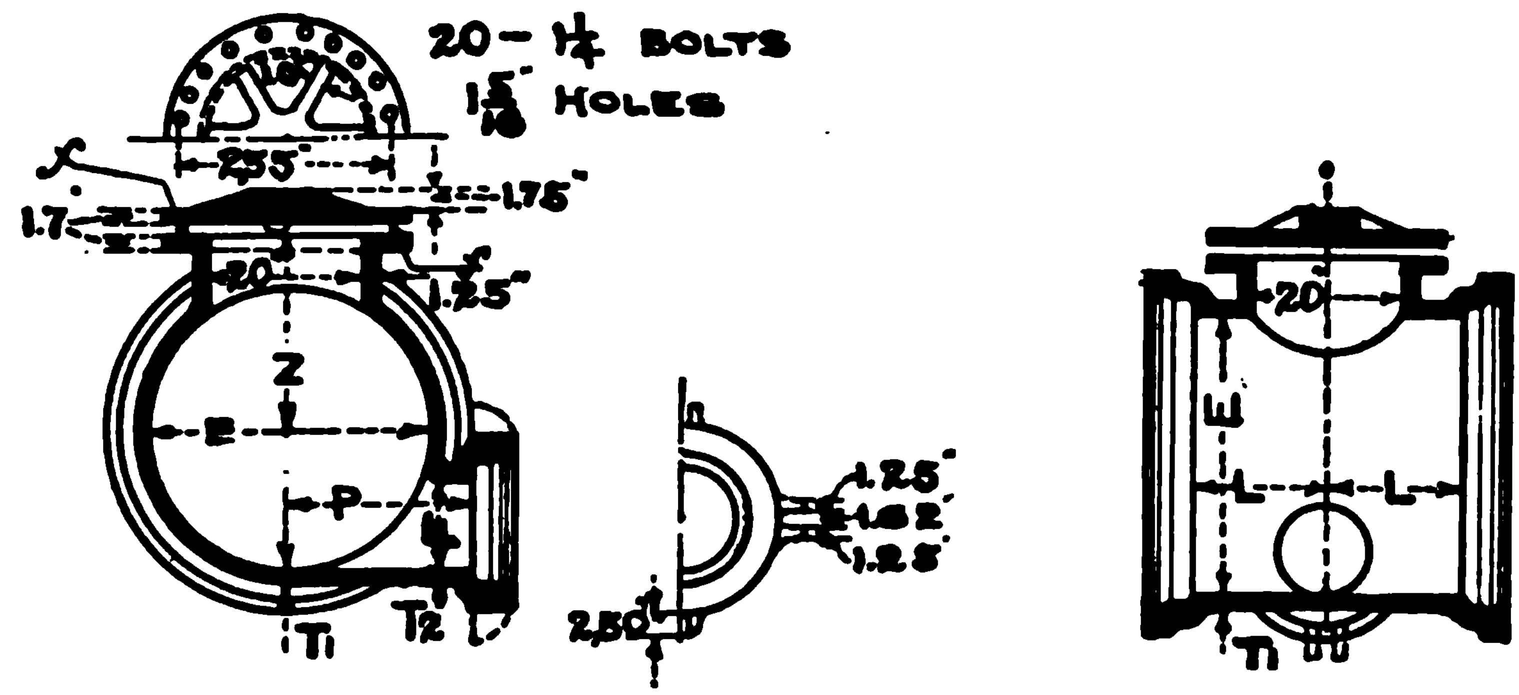


TABLE NO. 9.—BLOW-OFF BRANCHES WITH MANHOLES.

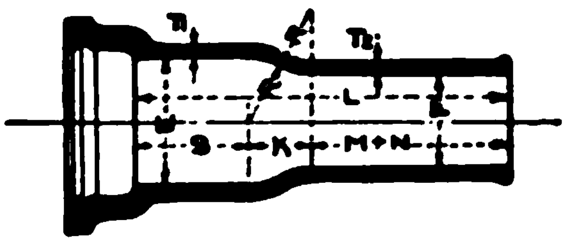
(Dimensions in Inches.)

Nominal Diameter.		L	P	N	T_1	T_2	Class.
E	F						
30	8	17	20	21	0.88	0.60	A
30	8	17	20	21	1.03	0.60	B
30	8	17	20	21	1.20	0.60	C
30	8	17	20	21	1.37	0.60	D
30	12	17	20	21	0.88	0.75	A
30	12	17	20	21	1.03	0.75	B
30	12	17	20	21	1.20	0.75	C
30	12	17	20	21	1.37	0.75	D
36	8	17	23	24	0.99	0.60	A
36	8	17	23	24	1.15	0.60	B
36	8	17	23	24	1.36	0.60	C
36	8	17	23	24	1.58	0.60	D
36	12	17	23	24	0.99	0.75	A
36	12	17	23	24	1.15	0.75	B
36	12	17	23	24	1.36	0.75	C
36	12	17	23	24	1.58	0.75	D
42	12	17	26	27	1.10	0.75	A
42	12	17	26	27	1.28	0.75	B
42	12	17	26	27	1.54	0.75	C
42	12	17	26	27	1.78	0.75	D
42	16	17	26	27	1.10	0.70	A
42	16	17	26	27	1.28	0.70	B
42	16	17	26	27	1.54	0.89	C
42	16	17	26	27	1.78	0.89	D
48	12	17	30	30	1.26	0.75	A
48	12	17	30	30	1.42	0.75	B
48	12	17	30	30	1.71	0.75	C
48	12	17	30	30	1.96	0.75	D

TABLE NO. 9 (*Continued*).

(Dimensions in Inches.)

Nominal Diameter.		L	P	N	T_1	T_2	Class.
E	F						
48	16	17	30	30	1.26	0.70	A
48	16	17	30	30	1.42	0.70	B
48	16	17	30	30	1.71	0.89	C
48	16	17	30	30	1.96	0.89	D
54	12	19	33	33	1.35	0.75	A
54	12	19	33	33	1.55	0.75	B
54	12	19	33	33	1.90	0.75	C
54	12	19	33	33	2.23	0.75	D
54	16	19	33	33	1.35	0.70	A
54	16	19	33	33	1.55	0.70	B
54	16	19	33	33	1.90	0.89	C
54	16	19	33	33	2.23	0.89	D
60	12	21	36	36	1.39	0.75	A
60	12	21	36	36	1.67	0.75	B
60	12	21	36	36	2.00	0.75	C
60	12	21	36	36	2.38	0.75	D
60	16	21	36	36	1.39	0.70	A
60	16	21	36	36	1.67	0.70	B
60	16	21	36	36	2.00	0.89	C
60	16	21	36	36	2.38	0.89	D



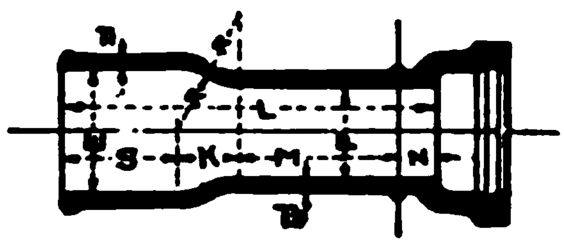


TABLE NO. 10.—REDUCERS.

TYPE 1.

(Dimensions in Inches.)

Nom. Diam.		S	K	M	N	L	R	T_1	T_2	Class.
E	F									
6	4	10	3.3	14.7	2	30	3	0.55	0.52	D
8	4	10	5.3	12.7	2	30	4	0.60	0.52	D
8	6	10	3.9	14.1	2	30	4	0.60	0.55	D
10	4	10	7.1	10.9	2	30	5	0.68	0.52	D
10	6	10	6.0	12.0	2	30	5	0.68	0.55	D
10	8	10	4.4	13.6	2	30	5	0.68	0.60	D
12	6	10	7.9	10.1	2	30	6	0.75	0.55	D
12	8	10	6.6	11.4	2	30	6	0.75	0.60	D
12	10	10	4.8	13.2	2	30	6	0.75	0.68	D

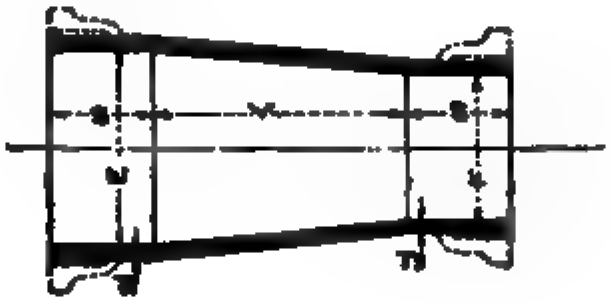


TABLE NO. 11.—REDUCERS.

TYPE 2.

(Dimensions in Inches.)

Nominal Diameter.		V	S	T_1	T_2	Class.
E	F					
14	6	20	8	0.66	0.55	A–B
14	6	[illegible]	8	0.82	0.55	C–D
14	8	20	8	0.66	0.60	A–B
14	[illegible]	20	8	0.82	0.60	C–D
14	10	20	8	0.66	0.66	A–B
14	10	20	8	0.88	0.68	C–D
14	12	[illegible]	8	0.66	0.66	A–B
14	12	20	8	0.82	0.75	C–D
16	6	20	8	0.70	0.55	A–B
[illegible]	6	20	8	0.89	0.55	C–D
16	8	20	8	0.70	0.60	A–B
16	[illegible]	20	8	0.89	0.60	C–D
[illegible]	[illegible]	[illegible]	8	0.70	0.68	A–B
16	10	20	8	0.89	0.68	C–D
16	12	20	8	0.70	0.70	A–B
16	[illegible]	20	8	0.89	0.75	C–D
16	14	20	[illegible]	0.70	0.66	A–B
16	14	20	[illegible]	0.89	0.82	C–D
18	8	[illegible]	8	0.75	0.60	A–B
18	8	20	[illegible]	0.96	0.60	C–D
18	10	20	8	0.75	0.68	A–B
18	10	20	[illegible]	0.96	0.68	C–D
18	12	20	8	0.75	0.75	A–B
18	12	20	8	0.96	0.75	C–D
18	14	[illegible]	8	0.75	0.66	A–B
18	14	[illegible]	8	0.96	0.82	C–D
18	16	20	8	0.75	0.70	A–B
18	[illegible]	20	[illegible]	0.96	0.89	C–D
20	10	26	8	0.80	0.68	A–B
20	10	26	8	1.03	0.68	C–D

TABLE NO. 11 (*Continued*).
(Dimensions in Inches.)

Nominal Diameter.		V	S	T_1	T_2	Class.
E	P					
20	12	20	8	0.80	0.75	A–B
20	12	20	8	1.03	0.75	C–D
20	14	26	8	0.80	0.66	A–B
20	14	26	8	1.03	0.82	C–D
20	16	26	8	0.80	0.70	A–B
[illegible]	16	26	8	1.03	0.89	C–D
20	18	26	8	0.80	0.75	A–B
20	18	26	8	1.03	0.96	C–D
24	14	26	8	0.89	0.66	A–B
24	14	26	8	1.16	0.82	C–D
24	16	26	[illegible]	0.89	0.70	A–B
24	16	26	8	1.16	0.89	C–D
24	18	26	8	0.89	0.75	A–B
24	18	26	8	1.16	0.96	C–D
24	20	26	8	0.89	0.80	A–B
24	20	26	8	1.16	1.03	C–D
30	18	26	8	0.88	0.75	A
30	18	26	8	1.03	0.75	B
30	18	26	8	1.20	0.96	C
[illegible]	[illegible]	26	8	1.37	0.96	D
30	20	26	8	0.88	0.80	A
30	20	26	8	1.03	0.80	B
30	20	26	8	1.20	1.03	C
30	20	26	8	1.37	1.03	D
30	24	26	8	0.88	0.88	A
30	24	26	8	1.03	0.89	B
30	24	26	8	1.20	1.16	C
30	24	26	8	1.37	1.16	D
36	20	32	8	0.99	0.80	A
36	20	32	8	1.15	0.80	B
36	20	32	8	1.36	1.03	C
36	20	32	8	1.85	1.03	D
36	24	32	8	0.99	0.89	A
36	24	32	8	1.15	0.89	B
36	24	32	8	1.36	1.16	C
36	24	32	8	1.58	1.16	D
36	30	32	8	0.99	0.88	A
36	30	32	8	1.15	1.03	B
36	30	32	8	1.36	1.20	C
36	30	32	8	1.58	1.37	D
42	20	32	8	1.10	0.80	A
42	20	32	8	1.28	0.80	B
42	20	32	8	1.54	1.03	C
42	20	32	8	1.78	1.03	D
42	24	32	8	1.10	0.89	A
42	[illegible]	32	8	1.28	0.89	B
42	24	32	8	1.54	1.16	C
42	24	32	[illegible]	1.78	1.16	D

TABLE NO. 11 (*Continued*).
(Dimensions in Inches.)

Nominal Diameter		V	S	T_1	T_2	Class.
E	F					
42	30	32	8	1.10	0.88	A
42	30	32	8	1.28	1.03	B
42	30	32	8	1.54	1.20	C
42	30	32	8	1.78	1.37	D
42	30	66	8	1.10	0.88	A
42	30	66	8	1.28	1.03	B
42	30	66	8	1.54	1.20	C
42	30	66	8	1.78	1.37	D
42	36	32	8	1.10	0.99	A
42	36	32	8	1.28	1.15	B
42	36	32	8	1.54	1.36	C
42	36	32	8	1.78	1.58	D
42	36	66	8	1.10	0.99	A
42	36	66	8	1.28	1.15	B
42	36	66	8	1.54	1.36	C
42	36	66	8	1.78	1.58	[illegible]
48	30	32	8	1.26	0.88	A
48	30	32	8	1.42	1.03	B
48	30	32	8	1.71	1.20	C
48	30	32	8	1.96	1.37	D
48	[illegible]	132	8	1.26	0.88	A
48	30	132	8	1.42	1.03	B
48	30	132	8	1.71	1.20	C
48	30	132	8	1.96	1.37	D
48	36	32	8	1.26	0.99	A
[illegible]	36	32	8	1.42	1.15	B
48	36	32	8	1.71	1.36	C
48	36	32	8	1.96	1.58	D
48	36	132	8	1.26	0.99	A
48	36	132	8	1.42	1.15	B
48	36	132	8	1.71	1.36	C
48	36	132	8	1.96	1.58	D
48	42	32	8	1.26	1.10	A
48	42	32	8	1.42	1.28	B
48	42	32	8	1.71	1.54	C
48	42	32	8	1.96	1.78	D
48	42	132	8	1.26	1.10	A
48	42	132	8	1.42	1.28	B
48	42	132	8	1.71	1.54	C
48	42	132	8	1.96	1.78	D
54	36	66	8	1.35	0.99	A
54	36	[illegible]	8	1.55	1.15	B
54	36	66	8	1.90	1.36	C
54	36	66	8	2.23	1.58	D
54	36	132	8	1.35	0.99	A
54	36	132	8	1.55	1.15	B
54	36	132	8	1.90	1.36	C
54	36	132	8	2.23	1.58	D

TABLE NO. 11 (*Continued*).
(Dimensions in Inches.)

Nominal Diameter.		V	S	T_1	T_2	Class.
E	F					
54	42	66	8	1.35	1.10	A
54	42	66	8	1.55	1.28	A
54	42	66	8	1.90	1.54	C
54	42	[illegible]	8	2.23	1.78	D
54	42	132	8	1.35	1.10	A
54	42	132	8	1.55	1.28	B
54	42	132	8	1.90	[illegible]	[illegible]
54	42	132	8	2.23	1.78	D
54	48	66	8	1.35	1.26	A
54	48	66	8	1.55	1.42	B
54	48	66	8	1.90	1.71	C
54	48	66	8	2.23	1.96	[illegible]
54	[illegible]	132	8	1.35	1.26	A
54	48	132	8	1.55	1.42	B
54	48	132	8	1.90	1.71	[illegible]
54	48	132	8	2.23	1.96	D
60	36	66	8	1.39	0.99	A
60	36	66	8	1.67	1.15	[illegible]
60	36	66	8	2.00	1.36	C
60	36	[illegible]	8	2.38	1.58	D
60	36	132	8	1.39	0.99	A
60	36	132	8	1.67	1.15	B
[illegible]	36	132	8	2.00	[illegible]	[illegible]
60	36	132	8	2.38	1.58	D
60	42	[illegible]	8	1.39	1.10	A
60	42	66	8	1.67	1.28	[illegible]
60	42	66	8	2.00	[illegible]	C
60	[illegible]	66	8	2.38	1.78	[illegible]
60	42	132	8	1.39	1.10	A
60	42	132	8	1.67	[illegible]	B
60	42	132	8	2.00	1.54	C
60	42	132	8	2.38	1.78	D
60	48	66	8	1.39	[illegible]	A
60	48	66	8	1.67	1.42	[illegible]
60	48	66	8	2.00	1.71	C
60	48	66	8	2.38	1.96	[illegible]
60	48	132	[illegible]	1.39	1.26	A
[illegible]	48	132	8	1.67	[illegible]	B
60	48	132	8	2.00	1.71	C
60	48	132	8	2.38	1.96	D
60	54	66	8	1.39	1.35	A
60	54	66	8	1.67	1.55	[illegible]
60	54	66	8	2.00	1.90	C
60	54	66	8	2.38	2.23	D
60	54	132	8	1.39	1.35	A
60	54	132	8	1.67	1.55	[illegible]
60	54	132	8	2.00	1.90	C
60	54	132	8	2.38	2.23	D

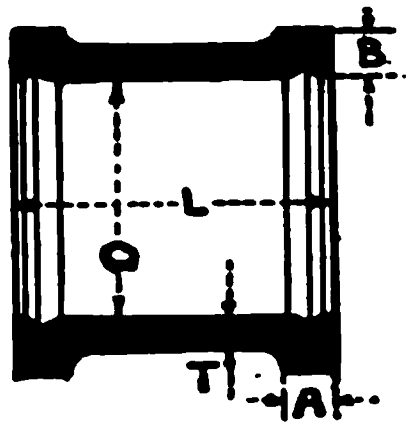


TABLE NO. 12.—SLEEVES.

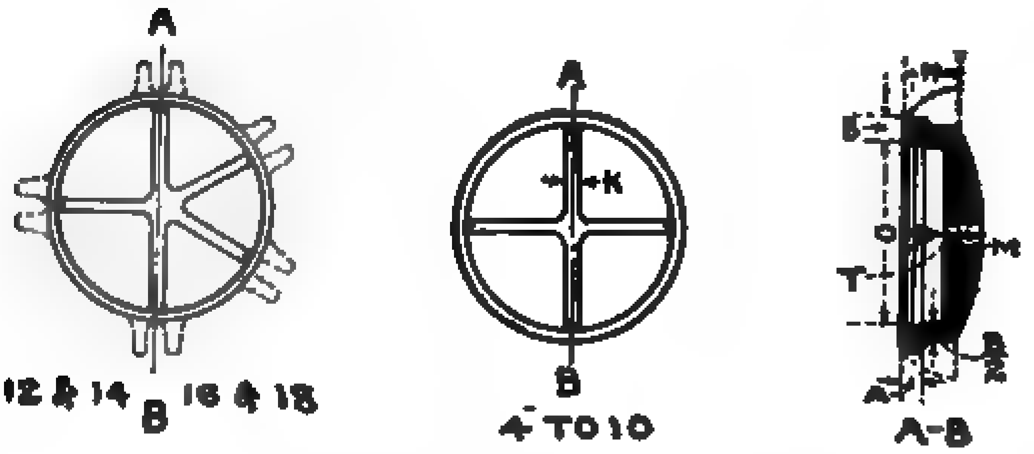
(Dimensions in Inches.)

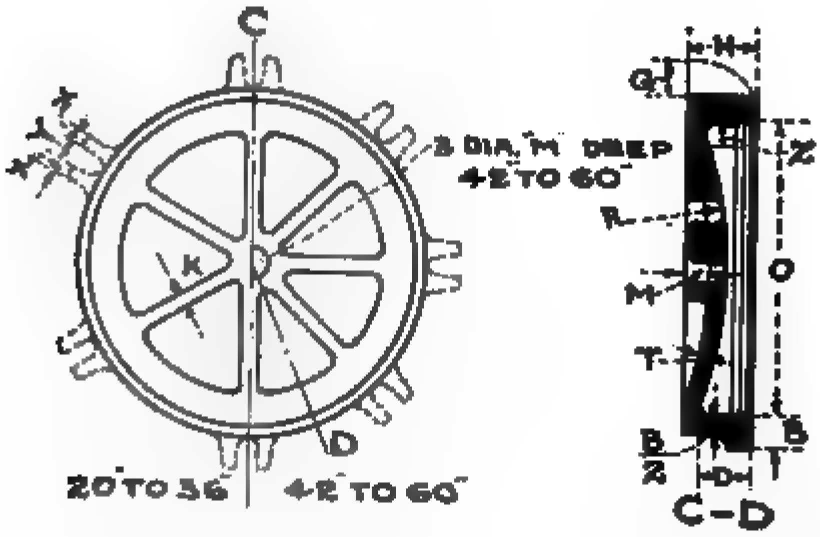
Nominal Diameter.	Class.	*A*	*B*	*L*	*O*	*T*
4	D	1.50	1.30	10	5.80	0.65
6	D	1.50	1.40	10	7.90	0.70
8	D	1.50	1.50	12	10.10	0.75
10	D	1.50	1.60	12	12.20	0.80
12	D	1.50	1.70	14	14.30	0.85
14	A–B	1.50	1.70	15	16.20	0.85
14	C–D	1.50	1.80	15	16.50	0.90
16	A–B	1.75	1.80	15	18.50	0.90
16	C–D	1.75	1.90	15	18.90	1.00
18	A–B	1.75	1.90	15	20.60	0.95
18	C–D	1.75	2.10	15	21.00	1.05
20	A–B	1.75	2.00	15	22.70	1.00
20	C–D	1.75	2.30	15	23.10	1.15
24	A–B	2.00	2.10	15	26.90	1.05
24	C–D	2.00	2.50	15	27.40	1.25
30	A	2.00	2.30	15	32.80	1.15
30	B	2.00	2.30	15	33.10	1.15
30	C	2.00	2.60	15	33.50	1.32
30	D	2.00	3.00	15	33.80	1.50
36	A	2.00	2.50	15	39.00	1.25
36	B	2.00	2.80	15	39.40	1.40
36	C	2.00	3.10	15	39.80	1.60
36	D	2.00	3.40	15	40.20	1.80
36	A	2.00	2.50	20	39.00	1.25
36	B	2.00	2.80	20	39.40	1.40
36	C	2.00	3.10	20	39.80	1.60
36	D	2.00	3.40	20	40.20	1.80
42	A	2.00	2.80	15	45.30	1.40
42	B	2.00	3.00	15	45.60	1.50
42	C	2.00	3.40	15	46.20	1.75
42	D	2.00	3.80	15	46.70	1.95
42	A	2.00	2.80	20	45.30	1.40
42	B	2.00	3.00	20	45.60	1.50
42	C	2.00	3.40	20	46.20	1.75
42	D	2.00	3.80	20	46.70	1.95

TABLE NO. 12 (*Continued*).

(Dimensions in Inches.)

Nominal Diameter.	Class.	*A*	*B*	*L*	*O*	*T*
48	A	2.00	3.00	15	51.60	1.50
48	B	2.00	3.30	15	51.90	1.65
48	C	2.00	3.80	15	52.50	1.95
48	D	2.00	4.20	15	53.10	2.20
48	A	2.00	3.00	20	51.60	1.50
48	B	2.00	3.30	20	51.90	1.65
48	C	2.00	3.80	20	52.50	1.95
48	D	2.00	4.20	20	53.10	2.20
54	A	2.25	3.20	15	57.70	1.60
54	B	2.25	3.60	15	58.20	1.80
54	C	2.25	4.00	15	58.90	2.15
54	D	2.25	4.40	15	59.50	2.45
54	A	2.25	3.20	20	57.70	1.60
54	B	2.25	3.60	20	58.20	1.80
54	C	2.25	4.00	20	58.90	2.15
54	D	2.25	4.40	20	59.50	2.45
60	A	2.25	3.40	15	63.90	1.70
60	B	2.25	3.70	15	64.50	1.90
60	C	2.25	4.20	15	65.30	2.25
60	D	2.25	4.70	15	65.90	2.60
60	A	2.25	3.40	20	63.90	1.70
	B	2.25	3.70	20	64.50	1.90
	C	2.25	4.20	20	65.30	2.25
	D	2.25	4.70	20	65.90	2.60





A and B as tabulated in Table No. 1.

$G = 2.50''$ for 12" to 24" incl. $G = 3.00''$ for 30" to 60" incl.
$X = 1.25''$ for 12" to 24" incl. $X = 1.50''$ for 30" to 60" incl.
$Y = 1.62''$ for 12" to 24" incl. $Y = 2.00''$ for 30" to 60" incl.

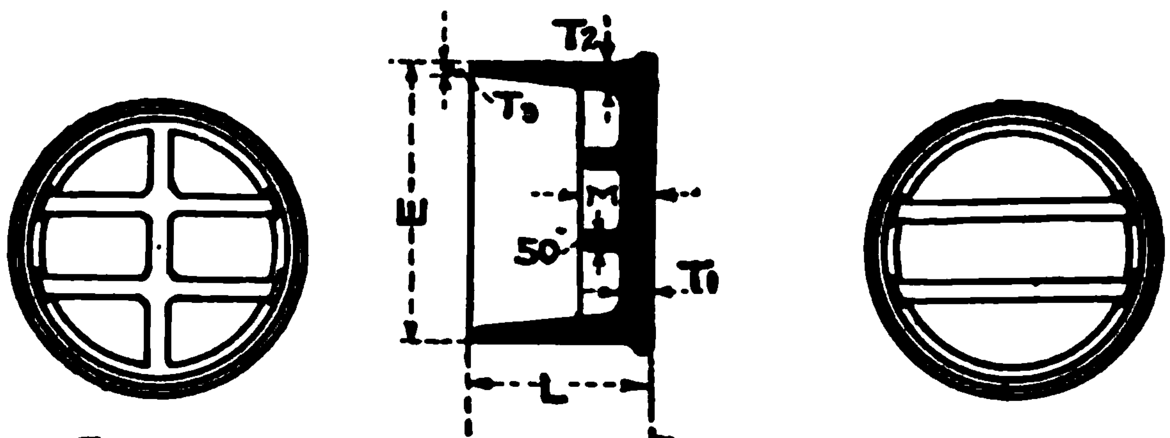
TABLE NO. 13.—CAPS.

(Dimensions in Inches.)

Nominal Diameter	D	O	H	T	M	K	Z	R	Class.
4	4.0	5.7	4.10	0.60	..	.	....	....	D
6	4.0	7.8	4.15	0.65	....	....	....	....	D
8	4.0	10.0	4.75	0.75	....	...	....	....	D
10	4.0	12.1	4.75	0.75	1.50	0.75	....	16.2	D
12	4.0	14.2	4.75	0.75	1.75	0.75	....	18.7	D
14	4.0	16.1	4.90	0.90	1.90	0.75	....	22.4	A–B
14	4.0	16.45	4.90	0.90	1.90	0.75	....	22.4	C–D
16	4.0	18.4	5.00	1.00	2.00	0.75	....	27.0	A–B
16	4.0	18.8	5.00	1.00	2.00	0.75	....	27.0	C–D
18	4.0	20.5	5.00	1.00	2.00	1.00	....	32.0	A–B
18	4.0	20.92	5.00	1.00	2.00	1.00	..	32.9	C–D
20	4.0	22.6	5.00	1.00	3.00	1.00	1.25	18.2	A–B
20	4.0	23.06	5.00	1.00	3.00	1.00	1.50	18.2	C–D
24	4.0	26.8	5.25	1.05	3.50	1.00	1.30	23.5	A–B
24	4.0	27.32	5.25	1.05	3.50	1.00	1.55	23.5	C–D

TABLE NO. 13 (*Continued*).
(Dimensions in Inches.)

Nominal Diam.	D	O	H	T	M	K	Z	R	Class.
30	4.5	32.74	5.75	1.15	3.50	1.15	1.30	34.8	A
30	4.5	33.00	5.75	1.15	3.50	1.15	1.50	34.8	B
30	4.5	33.40	5.75	1.15	3.50	1.15	1.70	34.8	C
30	4.5	33.74	5.75	1.15	3.50	1.15	1.90	34.8	D
36	4.5	38.96	6.00	1.25	4.00	1.25	1.63	44.0	A
36	4.5	39.30	6.00	1.30	3.95	1.25	1.88	44.0	B
36	4.5	39.70	6.00	1.35	3.90	1.25	2.08	44.0	C
36	4.5	40.16	6.00	1.40	3.85	1.25	2.30	44.0	D
42	5.00	45.20	7.00	1.40	4.00	1.40	2.00	63.5	A
42	5.00	45.50	7.00	1.50	3.90	1.40	2.25	63.5	B
42	5.00	46.10	7.00	1.60	3.80	1.40	2.55	63.5	C
42	5.00	46.58	7.00	1.70	3.70	1.40	2.80	63.5	D
48	5.00	51.50	7.00	1.70	4.00	1.50	2.10	76.5	A
48	5.00	51.80	7.00	1.90	3.80	1.50	2.40	76.5	B
48	5.00	52.40	7.00	2.00	3.70	1.50	2.70	76.5	C
48	5.00	52.98	7.00	2.10	3.60	1.50	3.00	76.5	D
54	5.5	57.66	7.5	1.90	4.50	1.50	2.20	82.0	A
54	5.5	58.10	7.5	2.00	4.40	1.50	2.50	82.0	B
54	5.5	58.80	7.5	2.10	4.30	1.50	2.80	82.0	C
54	5.5	59.40	7.5	2.20	4.20	1.50	3.10	82.0	D
60	5.5	63.80	7.5	2.00	4.50	1.50	2.30	99.0	A
60	5.5	64.40	7.5	2.10	4.40	1.50	2.60	99.0	B
60	5.5	65.20	7.5	2.20	4.30	1.50	2.90	99.0	C
60	5.5	65.82	7.5	2.30	4.20	1.50	3.20	99.0	D



3 RIBS SPIGOT BEAD 2 RIBS

E = actual outside diameter, Table No. 1.

TABLE NO. 14.—PLUGS.
(Dimensions in Inches.)

Nominal Diameter.	L	M	Number of Ribs.	T_1	T_2	T_3	Class.
4	5.5	....	....	0.50	0.40	0.20	D
6	5.5	....	....	0.60	0.40	0.20	D
8	5.5	2.0	2	0.60	0.40	0.20	D
10	6.0	2.0	2	0.70	0.50	0.20	D
12	6.0	2.0	2	0.75	0.50	0.20	D
14	6.0	2.0	2	0.70	0.50	0.20	A–B
14	6.0	2.0	2	0.75	0.50	0.20	C–D
16	6.5	2.0	3	0.70	0.50	0.30	A–B
16	6.5	2.0	3	0.80	0.60	0.30	C–D
18	6.5	2.5	3	0.75	0.60	0.30	A–B
18	6.5	2.5	3	0.85	0.60	0.30	C–D
20	6.5	2.75	3	0.85	0.60	0.30	A–B
20	6.5	2.75	3	1.00	0.60	0.30	C–D

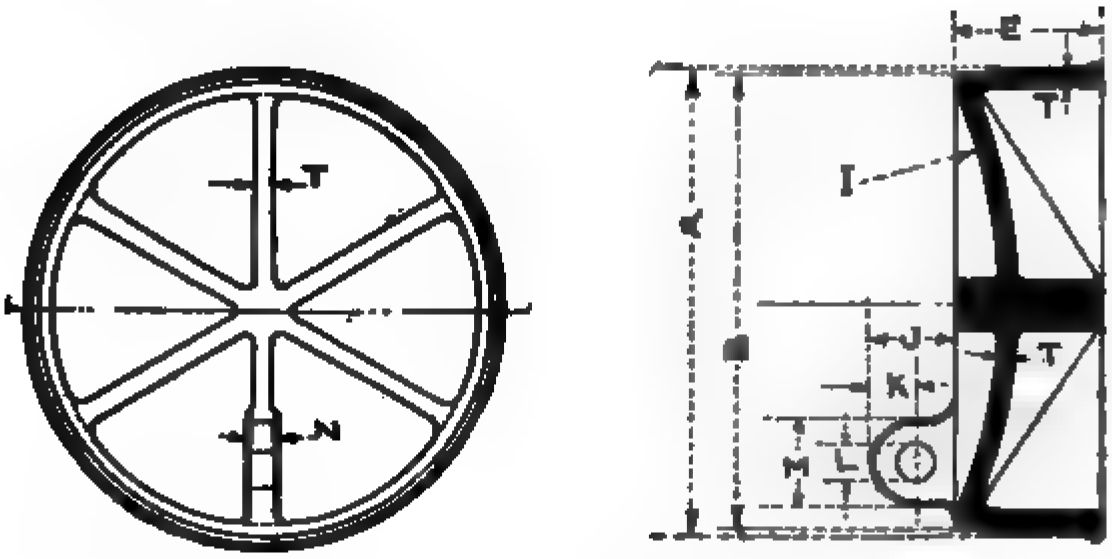


TABLE NO. 15.—BELL PLUG.

(Dimensions in Inches.)

Nom. Diam.	Class.	*A*	[illegible]	*E*	*J*	*K*	*L*	*M*	*N*	*I*	*T*
24	A–B	25.95	25.8	8	4 5	2.5	2 25	5 00	2 25	[illegible]	0 89
24	C–D	26 45	26 32	[illegible]	4.5	2.5	2.25	5.00	2 25	50	1.16
[illegible]	A	31.86	31 74	8	4.5	2 62	2 25	5.25	2.5	64	0 88
30	B	32.12	32 00	8	4.5	2.62	2.25	5.25	2.5	[illegible]	1 03
30	C	32.52	32.40	8	4.5	2.62	2.25	5.25	2.5	64	1.20
30	D	32.86	32.74	8	4 5	2 62	2 25	5 25	2.5	64	1.37
36	A	38.08	37.96	8	5.75	3.12	2.25	6.25	2.75	[illegible]	0.99
36	B	38 42	38.30	[illegible]	5.75	3.12	2 25	6.25	2.75	[illegible]	1 15
36	C	38.82	38 70	8	5 75	3 12	2 25	6 25	2.75	84	1 36
36	D	39.28	39.16	8	5 75	3.12	2.25	6.25	2.75	84	1 58
[illegible]	A	44.32	44 20	9	6 25	3.37	2.26	6 75	2 87	100	1.10
[illegible]	B	44.62	44 50	9	6 25	3 37	2 25	6.75	2.87	100	1 28
42	C	45.22	45 10	[illegible]	6 25	3.37	2 25	6.75	2.87	100	1.54
42	D	45 70	45 58	9	6.25	3 37	2 25	6.75	2 87	100	1.78
[illegible]	A	50.62	50.50	9	6.75	3.62	2 25	7.25	3.00	120	1.26
48	[illegible]	50 92	50.80	9	6 75	3.62	2.25	7.25	3.00	120	1.42
48	C	51.52	51.40	9	6 75	3.62	2.25	7.25	3.00	120	1.71
[illegible]	D	52.10	51.98	9	6.75	3.62	2 25	7.25	3.00	120	1.98
54	A	56.78	56.66	9	7.25	3.87	2.25	7.75	3.12	140	1.35
54	B	57.22	57.10	9	7.25	3.87	2.25	7.75	3.12	[illegible]	1.55
54	C	57.92	57.80	9	7.25	3.87	2 25	7 75	3.12	140	1.90
54	D	58.52	58.40	9	7.25	3.87	2.25	7.75	3.12	140	2.23
60	A	62.92	62.80	9	7 75	4 12	2.25	8.25	3.25	160	1.39
60	[illegible]	63.52	63.40	9	7.75	4.12	2.25	8.25	3.25	160	1.67
60	C	64.32	64 20	9	7 75	4 12	2.25	8.25	3.25	160	2.00
60	D	[illegible]	64.82	9	7.75	4.12	2.25	8.25	3.25	160	2.38

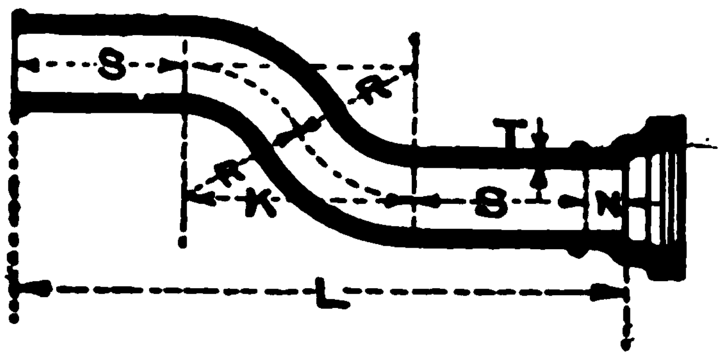


TABLE NO. 16.—OFF-SETS.
(Dimensions in Inches.)

Nominal Diameter.	*N*	*S*	*K*	*L*	*R*	*T*	Class.
4	2	10	13.85	35.85	8	0.52	D
6	2	10	24.25	46.25	14	0.55	D
8	2	10	26.00	48.00	15	0.60	D
10	2	10	27.70	49.70	16	0.68	D
12	2	10	29.45	51.45	17	0.75	D
14	2	10	31.20	53.20	18	0.66	A–B
14	2	10	31.20	53.20	18	0.82	C–D
16	2	10	32.90	54.90	19	0.70	A–B
16	2	10	32.90	54.90	19	0.89	C–D

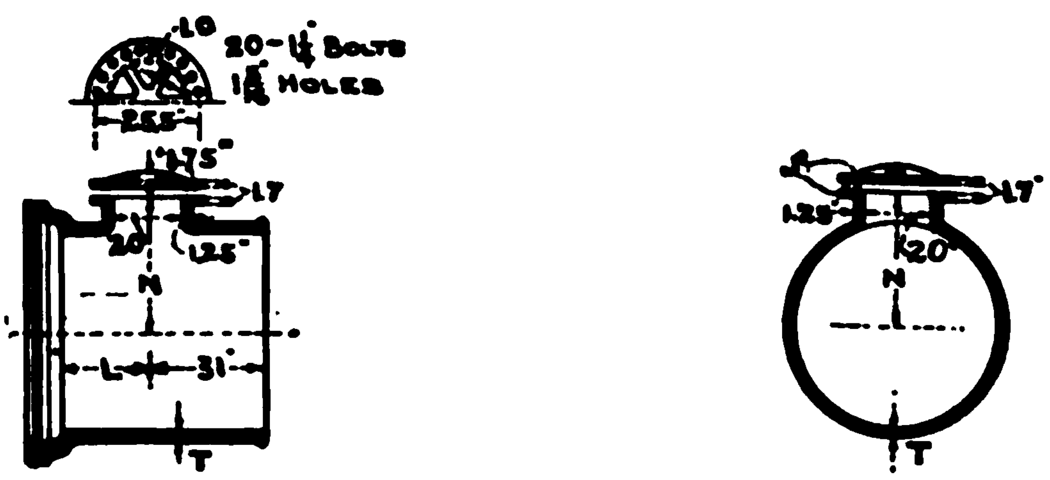


TABLE NO. 17.—MANHOLE PIPES.
(Dimensions in Inches.)

Nom. Diam.	*L*	*N*	*T*	Class.	Nom. Diam.	*L*	*N*	*T*	Class.
30	17	21	0.88	A	48	17	30	1.26	A
30	17	21	1.03	B	48	17	30	1.42	B
30	17	21	1.20	C	48	17	30	1.71	C
30	17	21	1.37	D	48	17	30	1.96	D
36	17	24	0.99	A	54	19	33	1.35	A
36	17	24	1.15	B	54	19	33	1.55	B
36	17	24	1.36	C	54	19	33	1.90	C
36	17	24	1.58	D	54	19	33	2.23	D
42	17	27	1.10	A	60	21	36	1.39	A
42	17	27	1.28	B	60	21	36	1.67	B
42	17	27	1.54	C	60	21	36	2.00	C
42	17	27	1.78	D	60	21	36	2.38	D

NOTE REGARDING LUGS ON BRANCHES.

Lugs of the form and dimensions given in the preceding tables are to be placed on the bells of side outlets on all branches, on outlets 12 inches in diameter and larger when desired.

NUMBER AND WEIGHTS OF LUGS ON OUTLETS OF DIFFERENT SIZES.

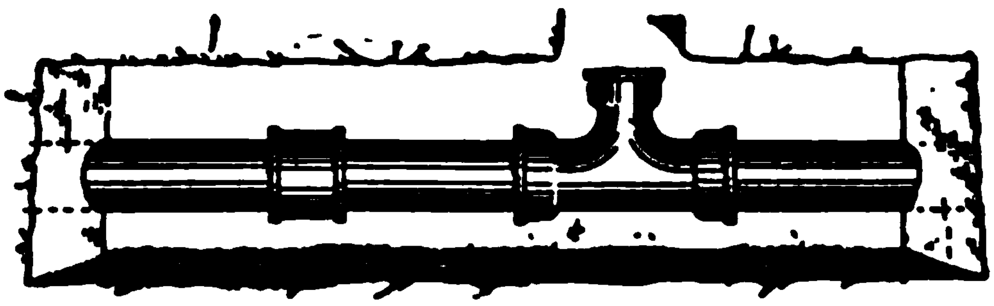
Diameter of Outlet, Inches.	No. of Pairs of Lugs.	Weight of Lugs on One Bell, Lbs.	Diameter of Outlet, Inches.	No. of Pairs of Lugs.	Weight of Lugs on One Bell, Lbs.
12	4	32	36	6	80
14	4	32	42	8	111
16	6	56	48	8	114
18	6	56	54 Class A and B	8	126
20	6	56	54 " C " D	8	134
24	6	56	60 " A " B	8	129
30	6	80	60 " C " D	8	137

Two pairs of lugs to be placed on the vertical axis of each bell, the others to be spaced at equal distances around the circumference.

If branches are made without lugs, the standard weights given in the table should be increased in accordance with the weights given above.

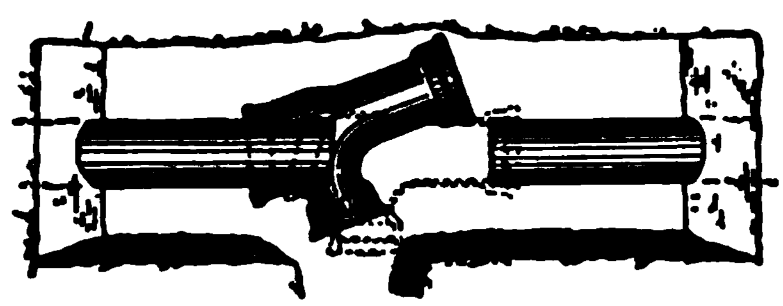
A METHOD OF "CUTTING-IN" SPECIALS.

Made in 4" to 16" diameters, inclusive, and especially designated for use where it is necessary to cut a street main for set-



Cut A.

ting an extra hydrant, the opening of a new street, or for the introduction of any other large service.



Cut B.

The above cuts illustrate the advantage of the "Cutting-in" Special, one end of which is enlarged back of the bell, and with

its face made slightly oblique to the axis of the Special. Thus it is readily inserted as shown and necessitates but two joints. At the back of the bell and parallel to its face there is a projection or rib which fits the main pipe and forms a stop for the yarn. The Special is so made as to be adapted to varying thicknesses of pipes and presents no difficulty in making up.

TABLE OF STANDARD SIZES, CUTTING-IN TEES.

Diameter in Inches.	Laying Length in Inches.	Approximate Weight in Lbs.	Will take Pipe of	
			Inside Diameter, Inches.	Thickness, Inches.
3×3	16	90	3	
4×4	19	100	4	$\frac{5}{16}$ to $\frac{9}{16}$
6×6	21	190	6	$\frac{3}{8}$ " $\frac{5}{8}$
8×8	23	290	8	$\frac{3}{8}$ " $\frac{3}{4}$
10×10	24	380	10	$\frac{7}{16}$ " $\frac{3}{4}$
12×12	24	580	12	$\frac{7}{16}$ " $\frac{7}{8}$
14×14	31	780	14	$\frac{1}{2}$ " $\frac{15}{16}$
16×16	31	950	16	$\frac{1}{2}$ " 1

Side outlets of different diameter than main run, to order on

Among the advantages in the use of this Special are diminished excavations, saving in joints and labor, absence of holding and blocking up of pieces, variation of an inch or two in length of piece cut out without causing trouble, and lessened length of time the water needs to be shut off. In addition, the "Cutting-in" Special may be used as an ordinary special if necessary, and where there is any uncertainty as to the location of side streets, it is cheaper to make the work continuous and "cut-in" branches with this Special as required.

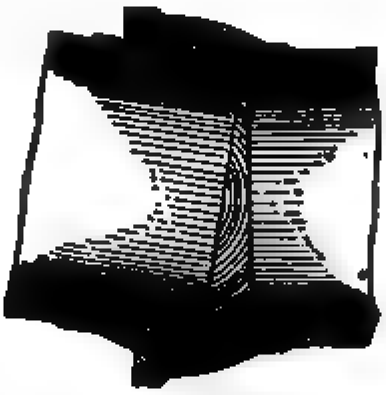
There are also SHORT LENGTHS OF PIPE with the PATENTED BELL and a SPIGOT or with the PATENTED BELL and an ORDINARY BELL END. Where a change of grade or alignment is not sufficient to require a curved pipe, this form of short pipe admirably answers the purpose. With them also a break can be repaired without a sleeve with the least excavation and with but one extra joint.

Under ordinary circumstances, however, the author recommends the method illustrated in Cut A.

FLEXIBLE-JOINT PIPE.

Made in Lengths to Lay 12 Feet.

The joint A is that usually employed, and admits of the lead gasket moving upon the interior surface of the bell, which is carefully machined. This design is sometimes modified by adding one or more lead grooves upon the spigot end.



A. Bell End, Machined Inside.

The design C is a more expensive joint, intended for the larger size of pipe, especially when they are used for conveying water under considerable pressure. This joint has a split retaining ring or collar bolted to the hub, as shown, forming a very secure

FLEXIBLE-JOINT PIPE.

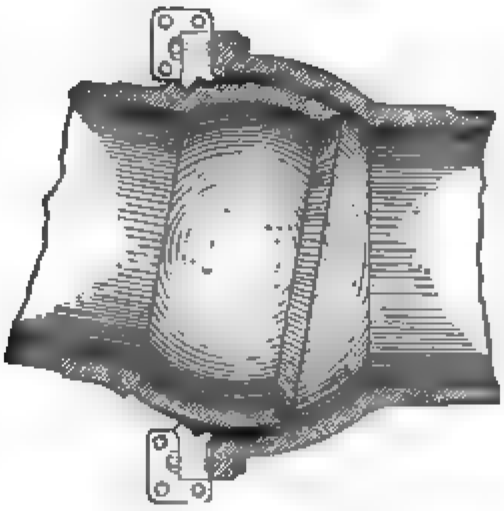
(Weights are approximate only.)

Inside Diameter of Pipe, Inches.	Thickness of Shell in Inches.	Weight per Length, Lbs.	Lead per Joint, Lbs.	Inside Diameter of Pipe, Inches.	Thickness of Shell in Inches.	Weight per Length, Lbs.	[illegible] per Joint, Lbs.
4	[illegible]	350	10	16	[illegible]	2190	77
4	[illegible]	280	10	16	[illegible]	1660	77
6	[illegible]	550	15	18	1	2640	93
6	[illegible]	440	15	18	[illegible]	1900	93
8	[illegible]	730	21	20	1 [illegible]	3220	112
8	[illegible]	590	21	20	[illegible]	2560	112
10	[illegible]	1000	[illegible]	24	1 [illegible]	4020	144
10	[illegible]	830	28	24	[illegible]	3440	144
12	[illegible]	1410	38	30	1 [illegible]	6190	181
12	[illegible]	1100	38	30	1	4870	181
14	[illegible]	1770	64	36	1 [illegible]	[illegible]	250
14	[illegible]	1450	64	36	1 [illegible]	6770	250

connection. For large diameters, these C joints made in short lengths may be used for convenience in handling or in connection with a line partly made up of ordinary bell-and-spigot pipe, though usually resulting in extra expense; full-length pipe, necessitating fewer joints, are generally to be preferred.

In standard flexible-joint pipe the maximum deviation permitted by the joint is 10°, taken in any direction.

In selecting the thickness of pipe for a submerged line, the internal pressure under which it will be in service is seldom the determining factor, as ample allowance should be made to mini-



C. Spigot End, Machined Outside and Fitted with Retaining Ring or Collar, Complete with Bolts.

mize the risk of breakage in laying, and to withstand external shocks from floating ice or other objects. The enlarged hubs naturally add materially to the weight of flexible-joint piping; and the thicknesses and weights suggested in the table may be taken as in line with good practice.

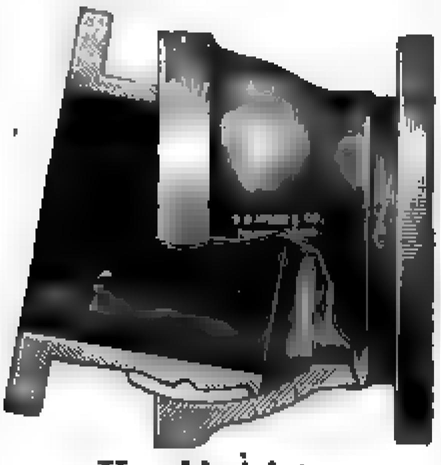
Made regularly in lengths to lay about twelve (12) feet.

A full assortment of flexible-joint pipe of design A, and of about the weights given in the table, usually in stock.

Design C to order only.

Short sections, design C, of sizes 20″ diameter and upward, for laying between ordinary pipe, to order.

Inquiries should state the approximate quantity of pipe, the thickness of shell, or weight per length, and time and place of delivery desired.



Knuckle-joints.

Made with ordinary bell, bell-and-spigot, or flanged ends. These short sections are used in making river crossings in connection with regular flange or bell-and-spigot pipe. The larger sizes with cast-iron or steel-riveted flange pipe make an excellent arrangement for intakes with floating screen. Flanged joints are drilled only to order.

KNUCKLE-JOINTS, SHORT SECTIONS.

STYLE A.

Inside Diameter of Pipe, Inches.	Thickness of Pipe, Inches.	Outside Diameter of Flange, Inches.	Laying Length.			Approximate Weight in Lbs.		
			Bell Ends, Inches.	Bell and Spigot, Inches.	Flange Ends, Inches.	Joint with Bell or Bell-and-spigot Ends, without Lead.	Joint with Flange Ends, without Lead.	Lead per Joint.
4	$\frac{7}{16}$	9	$10\frac{1}{2}$	$22\frac{1}{2}$	$10\frac{1}{2}$	100	80	10
6	$\frac{1}{2}$	11	$11\frac{1}{2}$	$23\frac{1}{2}$	$11\frac{1}{2}$	140	100	15
8	$\frac{9}{16}$	$13\frac{1}{2}$	$12\frac{1}{2}$	$24\frac{1}{2}$	$12\frac{1}{2}$	220	160	21
10	$\frac{5}{8}$	16	$14\frac{1}{4}$	$26\frac{1}{4}$	$14\frac{1}{4}$	310	230	28
12	$\frac{11}{16}$	19	16	28	16	440	350	38
14	$\frac{3}{4}$	21	$17\frac{3}{4}$	$29\frac{3}{4}$	$17\frac{3}{4}$	580	460	64
16	$\frac{7}{8}$	$23\frac{1}{2}$	$19\frac{1}{2}$	$31\frac{1}{2}$	$19\frac{1}{2}$	780	640	77
18	$\frac{15}{16}$	25	$21\frac{1}{4}$	$33\frac{1}{4}$	$21\frac{1}{4}$	990	800	[illegible]
20	1	$27\frac{1}{2}$	23	35	23	1280	1050	112
24	$1\frac{1}{16}$	32	$25\frac{1}{2}$	$37\frac{1}{2}$	$25\frac{1}{2}$	1700	1410	144
30	$1\frac{1}{4}$	$38\frac{3}{4}$	29	41	29	2720	2300	181
36	$1\frac{3}{8}$	$45\frac{3}{4}$	$32\frac{1}{2}$	$44\frac{1}{2}$	$32\frac{1}{2}$	4100	3570	250

Connecting Mains.—In a paper upon this subject Mr. Forstall advocates the following table to determine the size of connections and the method of making same:

NEW MAIN TO EXISTING MAINS.

Size of New Mains.	Size of Existing Mains.							
	30 in.	24 in.	20 in.	16 in	12 in.	8 in.	6 in.	4 in.
4 inch	Saddle P'ce or Hat Flg	[redacted] Piece	Saddle P'ce Split sl'ves	Insert Branch	Insert Branch	Insert Branch	Insert Branch	Insert Branch
6 inch	"	"	"	"	"	"	"	
8 inch	"	"	"	"	"	"		
12 inch } 16 inch }	Insert Branch	Insert Branch	Insert Branch	" "	"			
20 inch	"	"	"					
24 inch	"	"						
30 inch	"							

Tools for Laying Cast-iron Pipes.—After the material, including pipe and fittings, yarn, cement, or lead, has been ordered, the following tools will be needed for the work. The number of laborers required and the tools needed will, of course, vary with the size and length of the main to be laid. If a considerable main, say 4, 6, or 12 inch, to each fifty laborers two pipe handlers in trench, one yarner, four calkers, one lead-jointer, and one blocking man will be sufficient to start the men.

1 tapping-machine, $\frac{3}{4}''$ to 2″ taps.
4 calking-hammers.
2 Trimo wrenches, 18″ and 24″.
4 8-pound striking-hammers for use with dog-chisel in cutting cast-iron pipes.
2 15″ monkey-wrenches.
3 dog-chisels with handles.
1 2-lb. machinists' hammer.
1 12-lb. sledge-hammer.
2 paving-hammers.
4 sets calking-tools—8 pieces to the set.
6 lead-chisels.
4 split-chisels.
4 yarning-irons.
6 cold-chisels.
6 diamond-points.
2 5-ft. crowbars.
10 railroad tamping-bars.
6 4″ trowels.
1 10″ trowel.
2 18″ spirit-levels.
1 iron oil-can.

1 hand-saw.
1 2-man saw.
2 axes.
2 dozen street-lanterns with red globes.
1 dozen iron-plug dirt-pounders.
1 5-gallon kerosene-oil can.
1 15×30 galvanized-iron cement can.
1 100-ft. metallic tape measure.
1 12-ft. pipe-scraper for scraping dirt out of pipe.
1 wheelbarrow.
4 street-brooms.
1 salamander furnace with lead kettle for same.
2 small lead kettles for pouring joints.
2 pieces Manila rope 30 feet long.
2 tripods, A derrick or crabs.
2 Yale & Town chain-block, or similar make.
4 tunneling-shovels.
90 railroad-picks.
40 pick-handles.
60 sharp-nose D-handle shovels.
10 flat-nose D-handle shovels for bottom work and street-cleaning.
1 lot assorted gas-bags. These should never be left around in the tool-box, but should be called for as needed.
6 12×18×4″ galvanized-iron cement pans.
4 galvanized water buckets.
4 pairs rubber gloves.
Wooden plugs or stoppers to fit various size mains.
2 tool-boxes—1 for lighter material and 1 for picks, shovels, crowbars, sledges, etc.
1 or more three-wheel pipe-cutters to cut from ¾″ to 2″.
1 threading-machine ¾″ to 2″, or Beaver die stock and portable vise.
2 slings of rope.
6 forks (for separating gravel).
2 sets of Lawn horseshoes for tamping (discretionary).
1 set C. I. pipe-cutters, Hall or Rodfield type, with extra links.

Under some circumstances on long lines a pneumatic hammer, the compressor being driven by portable gasoline engine and the hammer fitted with calking-tools, may be used to advantage.

Wrought-iron Low-pressure Mains.—In laying wrought-iron mains the preparation to be made is the same as for cast-iron mains, with the exception that it is not customary in laying low-pressure natural-gas mains to make any provision for laying to grade. There is, of course, some difference in the tools required

for the work. In addition to the ordinary tools required by the laborers for digging the trench, etc., the following tools will be needed by the pipe-layers.

2 sets stocks and adjustable (retreating dies) for rechasing and cleaning threads.

Swabs for cleaning out the different-size mains.
2 pipe-jacks and boards.
4 pairs of tongs for each size main to be laid.
2 sets of chain-tongs.
Diamond-point chisels.
Cape-chisels.
Machinists' hammers.
Crowbars.
1 large air-pump (may be power driven) and gage.

The lay-tongs are pipe-tongs made for this kind of work. They are very long, are built heavy, and the bit is held in place by a wedge, and having four sides can be turned and a fresh biting edge obtained. Chain-tongs are best for fittings.

Where the work is extensive and a long line of pipe to be run, a power winch, with two hand-wheels and a chuck for holding the pipe, may be used to advantage for screwing home pipe, the joint being started by hand and several lengths being screwed at one operation.

Blasting.—Where it is necessary to blast in close quarters, or where there is any danger from flying missiles, this danger can be obviated or reduced to the minimum by including in the equipment a heavy rope net under which is placed a lighter rope net, the sides being weighed down by heavy timbers and stones. The mesh of the nets should not exceed three to four inches and the net laid slack.

Service Gang and Tools.—A service gang usually consists of one fitter and his helper and three to six laborers. A competent fitter may be foreman of this gang. In addition to the service wagon containing pipe-lengths, fittings, etc., and a portable vise, either with bench or attachable to a post, the equipment usual for each gang is:

3 sharp-nose D-handle shovels.
1 set adjustable stock and dies, Beaver type.
1 ratchet stock and dies, for trench and repair work.
1 long-handled shovel for tunneling.
4 railroad-picks with handles.
2 steel forks for separating dirt and gravel.
2 3′ 6″ crowbars.
1 street-broom.
1 tapping-machine, $\frac{3}{4}''$ to $2''$.

1 12-lb. sledge.
2 18″ and 124″ Trimo wrenches.
1 10″ Trimo wrench.
2 18″ wall-chisels.
1 3-wheel pipe-cutter (with extra wheels) for trench.
1 hatchet.
1 wheel pipe-cutter for vise work.
1 18″ bastard file.
1 2-lb. machinist's hammer.
1 oil-can and oil.
3 lanterns and red globes, 1 oil-can for same.
1 small test-pump and gage.

No laboring gang should be allowed to assemble upon the work without proper tool and supply equipment, as enormous delays frequently occur, due to the lack of some necessary tool, and the cost of the operation is correspondingly increased.

The use of the above inventories will be found of some convenience for checking up the equipment prior to the start of the day's work. Tool-books containing these inventories should be maintained and the equipment checked off at least twice a day, at which times either the tools or their parts should be in evidence, or the workman to whom issued held responsible.

Haulage.—An earth-cart should contain 1 cu. yd.

An earth-wagon (small size) 1.5 cu. yds.

An earth-wagon (large size) 3 cu. yds.

Wheelbarrow, 0.1 cu. yd.

One single load of earth = 27 cu. ft. = 21 bushels.

One double load of earth = 54 cu. ft.

One cu. yd. of gravel = 18 bu. (in the pit).

One cu. yd. of gravel = 24 bu. (when dug).

When formed into embankments gravel sinks ¼ in height and decreases ⅛ in bulk.

Earth (well-drained) will stand in embankments about 1½ to 1. (O'Connor.)

Weight of Yarn.—In making lead joints for cast-iron mains the weight of calking-yarn necessary is about as follows:

WEIGHT OF YARN PER JOINT.

Diameter Pipe, Inches.	Weight of Yarn, Ounces.	Diameter Pipe, Inches.	Weight of Yarn, Ounces.
3	3 to 3¼	12	10
4	3¼	16	12
6	4¾	20	14½
8	5¾	23	21½
10	6½	30	22

Economic Sizes of Purifying-boxes (Newbiggin's 6th Edition).—"Where there are intended to be four purifiers (what we term the four-box system), three always in action, the maximum daily (24-hour) make of gas, expressed in thousand cubic feet, multiplied by the constant 0.6, will give the superficial area in feet for each purifier." Or 60 square feet of area in each box per 100,000 cubic feet make per 24 hours.

(Mr. J. A. P. Crisfield, representing the most approved American practice.)

Assuming a time contact of 60 seconds (oxide of iron),

$$60=\frac{3600V}{3R},$$

where V is volume of oxide in cubic feet (between inlet of first box and point of test); R equals rate of "make per hour."

This "volume of oxide" may of course be divided by any number necessary to determine the various sizes of boxes found to be convenient.

Or the equation may be simplified to read

$$R=20V;$$

or the volume of oxide between the inlet of the purifiers and the completion of treatment for sulphureted hydrogen must be 1/20 of the rate of flow of gas per hour.

This rate of flow should be based upon the maximum or "peak" load of the year's output. Due allowance should of course be made in the installation of boxes for an increase of manufacture. It is also based upon the purification of carburetter water-gas, and should be increased approximately one-third in area of square feet for coal-gas.

Mr. Crisfield's formula, being based upon an equation between cost of installation, interest, and depreciation of apparatus of boxes, and the cost of labor and operation, undoubtedly constitutes the highest authority for American engineers.

SUBJECT-INDEX.

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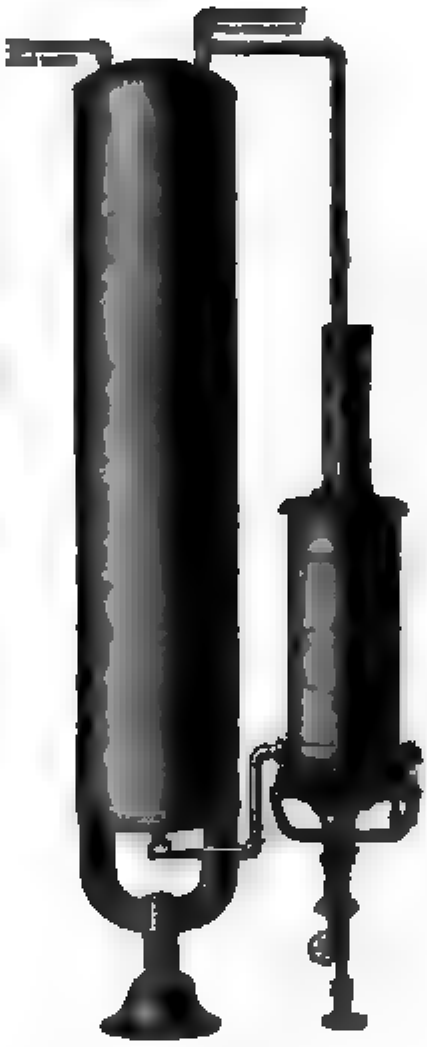

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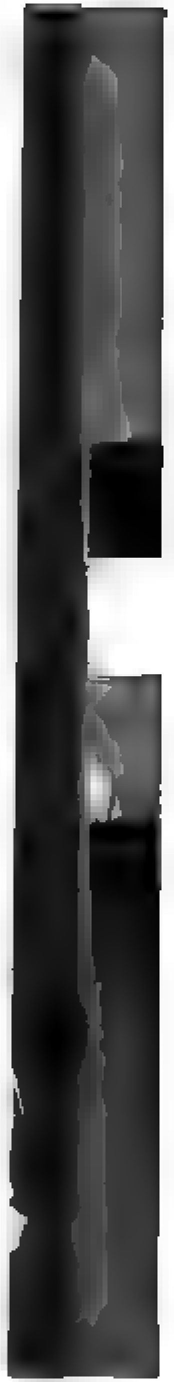

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